ISSUES IN MODELING MILITARY SPACE

THESIS

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Abstract
This research is a framework for understanding issues in modeling the military aspect of space, with particular regard to capturing its value. Space power is a difficult and far-reaching topic, with implications that go beyond the military aspects. The United States military increasingly relies on space-based systems and information for success in daily operations. Telecommunications, navigation and timing, intelligence, surveillance, reconnaissance, and weather prediction are instances of services that have become dependent on satellite systems. If this reliance on space is not fully understood, U.S. national security will be at risk as the result of space information degradation or denial. This research effort attempts to break new ground in organizing the interactions and interdependencies among space doctrine, space systems, system owner/operators, and space-based information users. An illustrative example, using GPS, is then examined to explore the approach. Analysis of GPS as it affects JDAM accuracy is modeled using the GPS Interference And Navigation Tool (GIANT).

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ISSUES IN MODELING MILITARY SPACE

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ISSUES IN MODELING MILITARY SPACE

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Peter F. Olsen

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ABSTRACT

This research is a framework for understanding issues in modeling the military aspect of space, with particular regard to capturing its value. Space power is a difficult and far-reaching topic, with implications that go beyond the military aspects. The United States military increasingly relies on space-based systems and information for success in daily operations. Telecommunications, navigation and timing, intelligence, surveillance, reconnaissance, and weather prediction are instances of services that have become dependent on satellite systems. If this reliance on space is not fully understood, U.S. national security will be at risk as the result of space information degradation or denial. This research effort attempts to break new ground in organizing the interactions and interdependencies among space doctrine, space systems, system owner/operators, and space-based information users. An illustrative example, using GPS, is then examined to explore the approach. Analysis of GPS as it affects JDAM accuracy is modeled using the GPS Interference And Navigation Tool (GIANT).

ISSUES IN MODELING MILITARY SPACE

I. INTRODUCTION

General Issue

The United States, and the world in general, increasingly relies on space-based systems. According to The Commission to Assess United States National Security Space Management and Organization (aka, Space Commission), America's interest in space includes the following:

- Promote the peaceful use of space.
- Use the nation's potential in space to support U.S. domestic, economic, diplomatic, and national security objectives.
- Develop and deploy the means to deter and defend against hostile acts directed at U.S. space assets and against the uses of space hostile to U.S. interests. (Space Commission, 2, 7)

Domestic and economic applications of space include navigation and timing, weather forecasting, geothermal imaging, pager and cellular service, television, telephone, radio, and other forms of communications. In order to meet national security objectives, deter foreign aggression, and defend U.S. interests, the military has more specialized uses for satellites. These include those listed above, as well as a variety of intelligence-gathering functions. These military space-based platforms provide our national leaders with the capability to communicate with frontline forces from any point on the globe, detect and investigate potential threats to allied forces or nations, pinpoint

enemy assets for use in munitions targeting, support guidance of precision munitions, and deter potential crises from affecting United States or allied national interests via intelligence-gathering applications. As nations and citizens become more technologically adept, space-based assets may develop more uses than planned for in their original mission design. This expansion of uses results in an increased reliance by the military, as well as society, on space-based technologies. As this reliance grows, so does our vulnerability to attacks on these space-based systems.

> As space products and services become ever more interwoven with our nation's politics, economics, culture, and security, they become an increasingly lucrative target for potential adversaries. With such growing dependence, a future foe could gain an advantage by denying, disrupting, or destroying our ability to access and use space. (Long Range Plan, 19)

For example, the use of GPS has grown well beyond its original military applications. GPS is used today to track packages, survey land, aid hikers and hunters in land navigation, aid search and rescue personnel in locating lost or injured personnel, and a variety of other commercial applications. Investment banks, cellular companies, paging/computer networks, and electrical utilities also use GPS for time synchronization (Klotz, 12). Banks with international branches must have time synchronization among their widely dispersed locations to calculate interest and correctly handle various transactions. Paging, cellular, and computer networks all use GPS-based time synchronization to communicate electronically. The Federal Aviation Administration (FAA) uses GPS for its Terminal Doppler Weather Radar system as a reliable time source (Houck, 1).

As society becomes increasingly reliant on space-based technology, questions arise concerning our vulnerability to its loss; what happens if a specific technology is

unavailable due to natural or man-made intervention? On March 13, 1989, the largest solar flare in half a century caused a magnetic storm that destroyed a power transformer in New Jersey and disabled the entire Hydro-Quebec electrical power grid for the Province of Quebec, Canada, resulting in a blackout for the entire province (Thompson, Reuters). This same storm also caused increased atmospheric drag in low-earth orbit (LEO) resulting in USSPACECOM having to recompute trajectories for about 1,300 objects (Odenwald).

A similar solar storm on July 17, 2000 caused minor problems, including the disruption of satellite data transfer, resulting in erroneous data from weather satellites (GOES-8) (Reuters). A more recent geomagnetic storm in August 2001 interfered with microwave communications, hand-held radiophones, and navigation systems in much of Canada and the northern tier of the U.S. (Siegel, 1). The storm was so intense that the Aurora Borealis could be seen as far south as El Paso, Texas. In addition, the recent Leonid meteor shower in mid-November caused concern among astrophysicists that the particles entering the near-earth environment might damage satellites (CNN, 1). Solar flare radio noise, solar radiation, and solar flares are listed as potential environmental impacts in the Joint Publications (Joint Pub IV-5).

Unfortunately, satellite disruption is not limited to natural events. Satellite transmissions can be jammed or disrupted like other types of transmissions. A handheld Russian GPS jamming device is powerful enough to disrupt an aircraft's GPS receiver out to 192 kilometers (Space Commission, Ch 2, 20). Jamming and natural space events can have a tremendous affect on civilian and military satellite applications. Our increasing dependence on space-based technology forces us to address the issue of the

effects and potential problems if those assets became unavailable. For instance, how would the way we wage war change if a space system (or systems) were degraded or lost completely? To determine the military effectiveness of space, one must know what space provides the warfighter and how, when, and where this information is used. This thesis investigates issues in modeling military uses of space, with particular attention given to how to begin measuring military effectiveness of space systems. It applies this method to a nominal GPS system as an illustrative demonstration of the method.

Background

The Department of Defense (DOD) and various U.S. space agencies are concerned with the potential vulnerabilities our nation's reliance on space-based platforms may create. The Space Commission's report to Congress indicates the nation's reliance on space assets could potentially lead to a "Space Pearl Harbor" situation (Space Commission, Executive Summary, viii). "We know from history that every medium—air, land, and sea—has seen conflict. Reality indicates that space will be no different" (Space Commission, Executive Summary, x). In a series of essays about the future of the Chinese military, written by high-ranking Chinese military authorities, space is clearly a new dimension in the battlefield. In fact, many Chinese military leaders support the view that future conflicts in space are inevitable and are preparing to meet that reality (Pillsbury, Part 4). Similarly, the Space Commission also states it is vital to national security to protect and defend the U.S. and its space assets from hostile action either from space or terrestrial forces (Space Commission, Executive Summary, vii).

In March 2000, General Eberhart, Commander in Chief, North American Aerospace Defense Command (NORAD); Commander in Chief, U.S. Space Command (USSPACECOM); and Commander, Air Force Space Command (AFSPC), described how the failure of one of four MilStar II satellites resulted in a 25% degradation in global tactical satellite secure communications capability (Eberhart, 13). This loss during a time of peace caused limited difficulties in tactical communications. However, in times of conflict or during critical military operations, this type of loss could be a crucial impediment to mission success and put lives at risk.

> The ability to restrict or deny freedom of access to and operations in space is no longer limited to global military powers. Knowledge of space systems and the means to counter them is increasingly available on the international market. Nations hostile to the U.S. possess or can acquire the means to disrupt or destroy U.S. space systems by attacking the satellites in space, their communications nodes on the ground and in space, or ground nodes that command the satellites. (Space Commission, 2, 19)

Identifying the critical space technologies the Air Force requires to complete its mission is a necessary first step. It is important to develop a methodology that can explain the extent of our dependence on these space assets.

> In the coming period, the U.S. will conduct operations to, from, in, and through space in support of its national interests both on earth and in space. As with national capabilities in the air, on land, and at sea, the U.S. must have the capabilities to defend its space assets against hostile acts and to negate the hostile use of space against U.S. interests. (Space Commission, 2, 13)

CIA Director George Tenet stated in his February 6, 2002 testimony to Congress that longstanding U.S. advantages in space surveillance “are eroding as more countries, including China and India, field increasingly sophisticated reconnaissance satellites” (Walter, 3). Awareness of these diminishing advantages, increasing interdependencies,

and an ability to measure our vulnerability is necessary while we improve methods to protect these space assets.

Air Force Space Command is concerned about the ability to quantify the impact of space on warfare and the warfighter. Some key questions that need to be addressed for establishing the military effectiveness of space are:

- What synergistic effects do satellites provide to mission accomplishment and how are these force-multipliers measured?
- Does the loss or degradation of space assets affect putting bombs on target?
- How do we measure damage and degradation in performance of satellites?
- At what point does satellite degradation start affecting mission effectiveness?
- At what points in the peace, pre-conflict, conflict, return-to-peace process is space critical? (Whitsel, 2001)

With respect to conventional operations, battle damage assessment (BDA) is well established, even though it may require satellite inputs and verification. However, with respect to information and satellite operations, our assessment of damage to a communications network of an enemy or allied intelligence satellite is less established. This is due to the nature of the space environment. It is relatively easy to assess damage done to a tank on the battlefield or determine the cause of its failure. However, when a space system fails or stops communicating, the current inaccessibility of space systems makes traditional BDA difficult. Telemetry data or radio emissions are typically more helpful in determining the cause of a failure.

Modeling can aide in the study of system failures or normal operations. There are two ways to study the operations and interactions of a system: experiment with the actual system or experiment with a model of the system (Law and Kelton, 4). Since spacelift

systems and payloads are extremely expensive, a methodology is required to imitate and experiment with a space-based system. A clear indication that simulation can be useful in determining what space brings to the fight is the following citation from the Space Commission.

> The military uses a variety of tools to simulate war-fighting environments in support of exercises, experiments, and war games. However, these tools have not been modernized to take into account the missions and tasks that space systems can perform. As a result, simulation tools cannot be used effectively to understand the utility of space-based capabilities on warfare. Further, the lack of modeling and simulation tools has prevented military commanders from learning how to cope with the loss or temporary interruption of key space capabilities, such as the Global Positioning System (GPS), satellite communications, remote sensing, or missile warning information. To support exercises, experiments and war games, the Department must develop and employ modeling and simulation tools based on measures of merit and effectiveness that will quantify the effects of space-based capabilities. (Space Commission, xxix)

Not only is modeling and simulation useful, it is required according to Presidential Decision Directive (PDD). PDD-NSC-49/NSTC-8, *National Space Policy,* as implemented by Department of Defense Directive (DODD) 3100.10, *Space Policy,* July 1999, which states:

> Space capabilities and applications shall be integrated into campaign-level and other models and simulations. Models and simulations shall focus on demonstrating the military worth and other value of both friendly and adversary space capabilities and applications to mission accomplishment. (Space Policy, 12)

Understanding and organizing doctrine and mission functionality of our various space-based systems, what they do, and how they interact is necessary to accurately model these systems.

Problem Statement

The purpose of this thesis is to take an initial step in clarifying issues in modeling the military effectiveness of space. This first step involves a review of available open-source literature in order to determine the current state of the art in modeling space assets. This requires a review of how space is handled in various combat models and simulations. The next step is the development of a general form of measuring the effectiveness of a system. This methodology is then applied to a nominal GPS example to determine its validity.

Research Approach

The research objective of this thesis was to develop an initial methodology AFSPC can use to aid in modeling the military effectiveness of space. To do this, the influences and interactions of the space systems, the command and control structures, and the end users of the information these systems provide must be understood. Current capabilities in the modeling and simulation of space systems also must be evaluated. An understanding of the various primary, secondary, tertiary, and other dimensional interactions is essential for modeling the various space systems.

A hierarchy was developed of the various responsibilities space systems have on the Air Force mission. These mission responsibilities are then further reduced to analyze actual system functions using modeling and simulation. We apply our methodology to catalogue space assets' various missions, functions, and interactions. Additionally, our approach will help identify the customers using these systems, the purpose of the system, and a determination of the military worth.

Scope/Limitations

This research will look at the interactions between a space system's functionality and its mission requirements using open-source data. The analysis of the particular space system (GPS) is notional since it is based on open-source information and limited to an unclassified level. GPS has an important mission and provides key functionality to the warfighter. This example will provide an understanding of how space systems influence the military mission—a key step toward defining the system's military worth.

Outline of Thesis

In Chapter II, a review of relevant literature with respect to space systems, doctrine, responsibility matrices, and project management is presented. In Chapter III, a coherent methodology is developed for understanding how the functionality and mission requirements of space systems interact. In Chapter IV, an application of the methodology using the GPS system and its relation to the warfighter is presented. The thesis concludes with a recommendation for future related research projects.

II. LITERATURE REVIEW

Introduction

This chapter reviews open-source literature dealing with international law, U.S. policy, Department of Defense and Air Force doctrine, long-range planning, space operations and systems, and project management. The purpose of this chapter is to gain an understanding, at the open-source level, about the mission and functionality of space-based systems, how they are used, how they interact, and what limitations exist.

International Law

To establish the military worth of space, the current limits on the military use of space must be understood. International law, international treaties, and national policy place limits on military uses of space. Prohibited activities include: nuclear weapon testing in space, the delivery of weapons of mass destruction from space, and offensive operations from space. These documents also prohibit claims of sovereignty by a nation on any celestial body or extraterrestrial territory. Table 1, taken from the *Air Force Space Handbook*, highlights the key areas in international law or treaties limiting the military use of space. The U.S. maintains the right to carry out actions in space not directly prohibited by these agreements and treaties.

Table 1. International Agreements that Limit Military Activities in Space

Agreement	Principle/Constraint
United Nations Charter (1947)	- Made applicable to Space by the Outer Space Treaty of 1967 - Prohibits states from threatening to use, or actually using, force against the territorial integrity or political independence of another state (Article 2(4)) - Recognizes a state's inherent right to act in individual or collective self-defense when attacked.
Limited Test Ban Treaty (1963)	- Bans nuclear weapons tests in the atmosphere, in outer space, and underwater. - States may not conduct nuclear weapon tests or other nuclear explosions (i.e., peaceful nuclear explosions) in outer space or assist or encourage others to conduct such tests or explosions (Article 1).
Outer Space Treaty (1967)	- Outer space and celestial bodies are not subject to national appropriation by claim of sovereignty, use, occupation, or other means (Article 11). - Space activities shall be conducted in accordance with international law, including the UN Charter (Article III). - The Moon and other celestial bodies are to be used exclusively for peaceful purposes (Article IV) and free for use by all states (Article 1). - Nuclear weapons and other weapons of mass destruction (such as chemical and biological weapons) may not be placed in orbit, installed on celestial bodies, or stationed in space in any other manner (Article IV). - A state may not conduct military maneuvers: establish military bases, fortifications, or installations; or test any type of weapon on celestial bodies. Use of military personnel for scientific research or other peaceful purpose is permitted (Article IV). - States are responsible for governmental and private space activities, and must supervise and regulate private activities (Article IV). - States are internationally liable for damage to another state (and its Citizens) caused by its space objects (including privately owned ones) (Article VII). - States retain jurisdiction and control over space objects while they are in space or on celestial bodies (Article VII). - States must conduct international consultations before proceeding with activities that would cause potentially harmful interference with activities of other parties (Article IX). - States must carry out their use and exploration of space in such a way as to avoid harmful contamination of outer space, the Moon, and other celestial bodies, as well as to avoid the introduction of extraterrestrial matter that could adversely affect the environment of the Earth (Article IX). - Stations, installations, equipment, and space vehicles on the Moon and other celestial bodies are open to inspection by other countries on a basis of reciprocity (Article XII).
Antiballistic Missile (ABM) Treaty (1972) Dec 13, 2001 U.S. withdraw from the ABM Treaty (Bush)	- Between the US and USSR. - Prohibits development, testing, or deployment of space-based ABNI systems or components (Article V). - Prohibits deployment of ABM systems or components except as authorized in the treaty (Article I). - Prohibits interference with the national technical means a party uses to verify compliance with the treaty (Article XII).
Liability Convention (1972)	- A launching site is absolutely liable for damage by its space object to people or property on the Earth or in its atmosphere (Article II). - Liability for damage caused by a space object, to persons or property on board such a space object, is determined by fault (Article III).
Convention on Registration (1974)	- Requires a party to maintain a registry of objects it launches into Earth orbit or beyond (Article II). - Information of each registered object must be furnished to the UN as soon as practical, including basic orbital parameters and general function of the object (Article IV).
Environmental Modification Convention (1980)	- Prohibits military or other hostile use of environmental modification techniques as a means of destruction, damage, or injury to any other state if such use has widespread, long-lasting, or severe effects (Article I).

Source: Space Handbook, Vol. I, 55

These limitations are specific and still allow for a broad use of space. By not expressly denying its use in space, "international law implicitly permits the performance of traditional military functions as surveillance, reconnaissance, navigation, meteorology, and communications" (Space Handbook I, 57). Activities that are permitted include nonnuclear, non-ABM, conventional space-to-ground weapons and anti-satellite weapons. These uses of space by the military may be limited by U.S. national policy objectives, however. "Currently, there are no force application assets operating in space, but technology and national policy could change so that force application missions could be performed from platforms operating in space" (AFDD 2-2, 19).

The recent withdrawal by the United States from the 1972 ABM Treaty illustrates how national policy can change with respect to the military uses of space. Based on openly available information, no force application assets for any nation are currently operating in space.

National Space Policy

In 2000, Congress created the Space Commission. The Space Commission's charter was to assess the (Space Commission, Ch 1, 2):

- Exploitation of military space assets to support U.S. operations.
- Interagency coordination of national security space assets.
- Professional military education institutions' role in military space issues.
- The potential costs and benefits of:
    - Merging intelligence and non-intelligence aspects of national security space.
    - An independent national security space mission department and military service.

- A national security space mission corps within the Air Force.
- A position of Assistant Secretary of Defense for Space.
- A new program or budget mechanism to manage national security space.
- Any other change to existing DOD organizational structure for national security space management and organization.

Congress amended the Space Commission's charter in 2001, to include the following additional elements (Space Commission, 1, 2):

- Flag officers must have space, missile, or information operations experience.
- CINC SPACECOM must be rotated among the services.
- Removal of flight rating requirement for key officer positions.

These tasks form a comprehensive and far reaching understanding into how space is and should be used, organized, and managed by the Department of Defense, intelligence communities, civilian, and commercial organizations. Prior to the Space Commission, the arrangement and management of space did not provide a clear and focused attention to space (Space Commission, 2, 9). The Space Commission recommended several changes in the space organizational structure giving space a cabinet-level voice, clearer accountability, and responsibility. The result of the Space Commission study is a greater emphasis on the role space has in national security. In addition, the Space Commission recommended (Space Commission, 6, 90):

- Air Force Space Command (AFSPC) should be assigned responsibility for providing the resources to execute space research, development, acquisition, and operations, under the command of a four-star general. The Army and Navy would still establish requirements and develop and deploy space systems unique to each service.

- Amend Title 10 U.S.C. to assign the Air Force responsibility to organize, train, and equip for prompt and sustained offensive and defensive air and space operations. In addition, the Secretary of Defense should designate the Air Force as Executive Agent for Space within the Department of Defense.

The recent promotion and subsequent reassignment of General Lance Lord as Commander of AFSPC, together with the realignment of the Space and Missile Systems Center (SMC) from Air Force Materiel Command (AFMC) to AFSPC, provides a clear indication that the Space Commission's recommendations are being implemented.

Other important policy and planning documents include: the *National Security Space Master Plan*, *DOD Space Policy*, *Joint Vision 2020*, *USSPACECOM Long Range Plan*, and the *AFSPC Strategic Master Plan*.

Military Doctrine

Where policy is a plan or a course of action, "doctrine is a tool to translate national policy into military forces and employment strategy" (Newberry, 3). Table 2 highlights several differences between policy and doctrine. Table 2 clearly demonstrates the emphasis of doctrine on military effectiveness or worth.

Table 2. Policy versus Doctrine

Item	Policy	Doctrine
Source	Civilian Authorities	Military Leadership
Emphasis	Politically Derived	Military Effectiveness
Responsiveness	Quick	Slow, Incremental
Duration	Short	Long

Source: Newberry, 9

Joint doctrine is a necessary capstone requirement before any service-level doctrine can be established (Newberry, 5). However, in the absence of Joint doctrine on

space, the Air Force developed Air Force Doctrine Document (AFDD) 2-2, *Space Operations*, in 1998. This was the first space doctrine developed in the seven years since Air Force Manual 1-6, *Military Space Doctrine,* was rescinded in 1991. Joint doctrine for space during this time was non-existent until publication of a draft of Joint Publication 3-14, *Joint Doctrine: Tactics, Techniques, and Procedures (JTTP) for Space Operations,* in 1999. Without an officially approved joint doctrine, the military worth of space becomes less tangible and more difficult to assess.

Joint Pub 3-14 is currently under development by USSPACECOM. In its first draft, version dated January 1999, the space doctrine focus is on four mission areas: space control, force application, space support, and force enhancement (Joint Pub 3-14, vi).

The space control mission is composed of three functional areas: protection, prevention, and negation. Protection consists of both active and passive defensive measures to safeguard space-based assets from natural or man-made interference. Prevention is a form of deterrence through economic, diplomatic, or political means to avoid a hostile nation's use of space-based systems. Negation refers to measures to deceive, disrupt, deny, degrade, or destroy an enemy's space systems and services (Joint Pub 3-14, III-5).

Force application and space control, together, account for combat operations in space. Force application is the true offensive role in space and involves the employment of weapons targeting air, land, sea, or other space forces. Current national policy constrains the use of force from space. Future force application functions may consist of power projection, terrestrial defense, and ballistic missile defense (BMD) (Joint Pub 3-14, III-12, GL-8).

Space support represents the logistical footprint required to operate space systems. Spacelift/launch, satellite operations (telemetry, tracking, & commanding or TT&C), and space surveillance are the functional areas of space support (Joint Pub, III-11). Spacelift and launch refer to operations associated with delivering a system into orbit. TT&C refers to the actual control of a system while it is in orbit. Space surveillance is a support function for tracking, identifying, and cataloging any and all items in orbit in support of launch operations (Joint Pub 3-14, III-11). This important function is used to support the placement of future systems into orbit, identify potential threats, and avoid collision with existing systems or space debris (Joint Pub 3-14, III- 4).

The Force enhancement mission is a combat support mission. The various functional areas provide situational awareness to the warfighter. Because of this situational awareness, the force enhancement mission has the most direct impact on the warfighter (Joint Pub 3-14, III- 8). The functional areas for force enhancement are: surveillance and reconnaissance, environmental monitoring, communications, imagery/global geospatial information and services, and navigation and timing.

Surveillance and reconnaissance provides the combatant commander intelligence on troop disposition, location, and intention. Surveillance and reconnaissance also provides early attack warning, targeting analysis, BDA, and COA opportunities (Joint Pub 3-14, App A). This allows the commander a greater variety of options when employing forces; e.g., tactics can be selected to give friendly forces a great advantage (Joint Pub 3-14, App A).

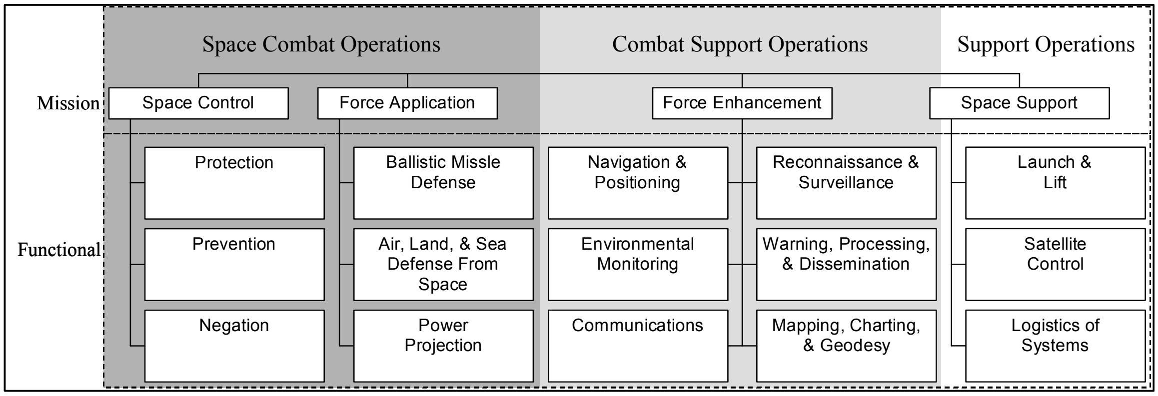
Environmental monitoring provides commanders with meteorological, oceanographic, and space environmental data. Weather forecast data is useful for

mission planning, targeting and weapon selection, timing, BDA and communications. Oceanographic data provides surface commanders with surface condition, swell height, depth, and water current information (Joint Pub 3-14, App B).

Communications are essential for command and control of forces in wartime and peacetime operations. With increased reliance on technologically advanced weapons, data transfer requirements will only increase. Video and audio communications provide necessary information to warfighters and mission planners. Satellite communications provide quick and secure communications at all levels of command from troops in the field to the combatant commander to the President and Secretary of Defense National Command Authority (Joint Pub 3-14, App C).

Imagery/global geospatial information and services provide "information on terrain, surface trafficability, oceanic subsurface conditions, beach conditions, and vegetation" (Joint Pub 3-14, App D). With this information, mission planners can identify specific avenues of approach, ingress/egress routes, and other mission requirements.

Navigation and timing provide very accurate three-dimensional location, velocity, and timing information to the warfighter. This is essential for today's precision-guided munitions and weapon systems.



Source: Created from Joint Pub 3-14

Figure 1. Space Mission and Functional Elements

Figure 1 graphically represents the mission and functional elements of space according to draft Joint Publication 3-14. These military uses of space fulfill basic information collection processes that were once only gathered by spies or scout troops. This information is required to successfully plan military operations. Sun Tzu wrote, "Know the enemy, know yourself; your victory will never be endangered. Know the ground, know the weather; your victory will then be total" (Huang, 13). Joint space doctrine is organized to aid in the collection and identification of this type of information to help carry out operational missions.

According to Joint Publication 3-14, USSPACECOM is the "single military organization responsible for military space operations" (Joint Pub 3-14, vi). As such, USSPACECOM's mission as a unified combatant command is to coordinate the use of space control, force application, space support, force enhancement, computer network defense, and computer network attack among the Army, Navy, and Air Force Space Commands. The first four missions are identical to the missions directed under Joint Publication 3-14. The two additional mission areas deal with the defense of and attack on

information, computers, and networks in terms of disruption, denial, degradation, or destruction.

AFSPC is the Air Force's major command responsible for providing trained space forces to USSPACECOM, and trained ICBM forces to the U.S. Strategic Command (USSTRATCOM). As the Executive Agent for Space, the AFSPC mission is to defend the United States through the control and exploitation of space. This mission is further divided into the four areas of space control, force application, space support, and force enhancement. While CINC USSPACECOM has also filled the role as CINC NORAD and AFSPC/CC, the Space Commission recommends discontinuing this practice. By separating AFSPC from USSPACECOM, CINC USSPACECOM can focus on long-term joint space issues and divorce himself from nearer term AFSPC issues (Space Commission, 6, 89).

Service-level doctrine should be more operational in scope than joint doctrine. "Space systems and capabilities enhance the precision, lethality, survivability, and agility of all operations—air, land, sea, and special operations" (AFDD 2-2, 3). These operational enhancement functions are similar to those assigned for airpower. The four functional areas listed in AFDD 2-2, are space control, application of force, enhancing operations, and supporting space forces. These areas directly correspond to those functions mentioned in joint doctrine. Some nominal operational power capabilities provided by space operations are depicted in Table 3.

Table 3. Nominal Space Capabilities

Space Control	Enhancing Operations				
Provide a space order of battle	Surveillance/ Reconnaissance	Navigation	Environmental Sensing	Communication	Theater Missile Warning
Detect attack and provide warning to space forces Defend against attack against space forces Detect, report, and track ballistic missile launches Disrupt, Deny, degrade, and destroy adversary space surveillance capabilities Deny Adversary access to US/ allied space systems Deceive, disrupt, deny, degrade, or destroy space platforms, payloads, sensors, links, launch facilities, satellite control, or information distribution centers as required by CINCs Deploy decoys, on-orbit spares, and residual capabilities as required to support military operations	Detect artificial disturbances (e.g., buried facilities, construction sites, etc.) Locate pre-surveyed missile launch locations Provide route and target information for mission planning Detect camouflage (artificial soft disturbances) Assess enemy movements, operations Provide warning of hostile acts and reconnaissance against US assets Detect, track, assess, and report air-breathing threats Detect, assess, and report nuclear detonations	Provide common navigation grid Provide common timing references Provide position, location, velocity for weapon accuracy, and ingress and egress Provide position, location, time for navigation, and silent rendezvous coordination	Provide data for radiation fallout patterns, intensity, and aerosol dispersion Provide wind and cloud temperature, and atmospheric moisture data in enemy area for weapon selection Monitor ionospheric disturbances and weather conditions which affect C4I Provide weather data over route and target Provide soil moisture, location of ice flows, precipitation, temperature, and snow cover data for trafficability Provide multispectral imagery data for maps and analysis Monitor solar wind and magnetic fields Determine when scintillation of US communication systems might occur	Provide raw data to assessment centers Provide assessed information to key decision makers Provide warning to forces Provide secure, survivable communications Provide taskings to forces Provide intertheater and intratheater communications Provide assessed information and data to forces Provide timely situational awareness and location information to forces Provide status of forces	Detect, report, and track ballistic missile launches

Source: AFDD 2-2, Appendix A

These space capabilities are employed throughout peacetime, escalation, conflict, and post hostilities (AFDD 2-2, 29). Figure 2 reflects how the realm of information superiority is integrated into the peace-war-peace cycle.

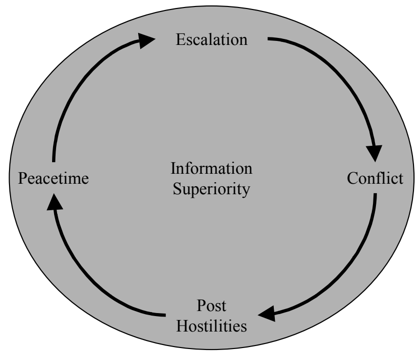


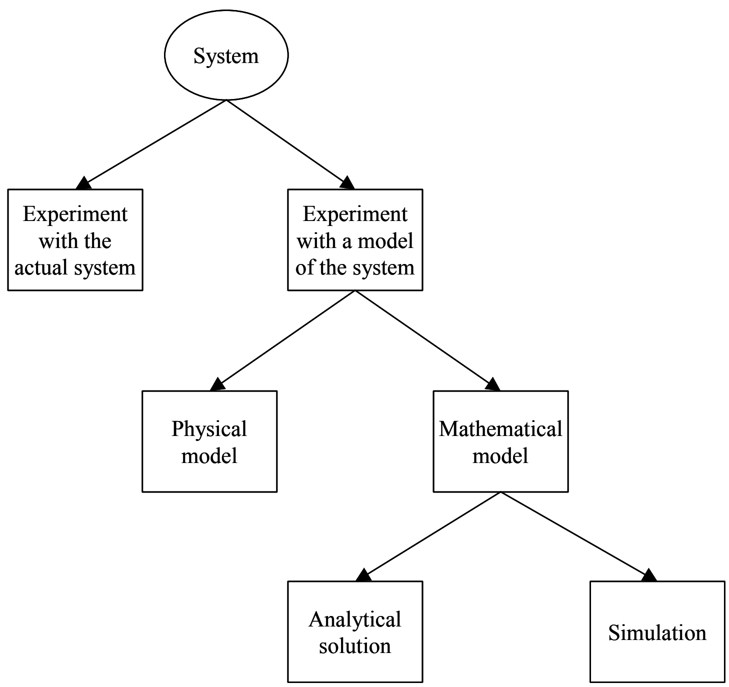
Figure 2. Space Employment Concepts

Space assets provide a significant proportion of the military's current information superiority capabilities via the mission functions already mentioned. The information provided by space is critical to decision makers and can provide global awareness and possibly diplomatic or political advantage that allows us to effectively respond to crises (AFDD 2-2, 29). This adds a dimension of time into the worth of space. Space provides both long-term and short-term benefits. Satellite imagery is crucial to both mission planning and execution. Intelligence gathering of possible future targets is a critical long-term role filled by space systems. Imagery of post-strike targets (BDA) is a critical short-term role by space systems.

Modeling and Simulation

In order to effectively model the military aspects of space, the interaction of space systems and their components, the performance of these components, and the users of these space systems must to be studied. Figure 3 illustrates various ways a system may be studied (Law & Kelton, 4). Modeling and simulation provides a capability for studying these interactions.

The first choice is to decide to experiment with the actual system or with a model of that system. A major factor in this decision is if it is cost-effective to modify the actual system (Law, 4). Another key factor is that in some cases, there is no real way (short of war) to test some systems. For example, for modifications to an existing airframe, it may be relatively simple to modify the airframe and test during flight-testing. However, if a new aircraft design is proposed, modeling the airframe in a wind tunnel first as an alternative to building a new aircraft and flight-testing it.



Source: Law, Figure 1.1

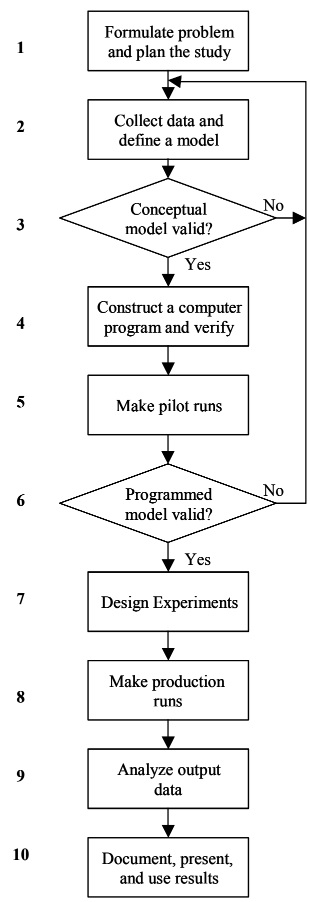
Figure 3. Ways to Study a System

The next choice is whether a physical model or mathematical model is required. A physical model is one in which a scaled replica of the system of interest is created and studied. A mathematical model represents a system by logical or quantitative measures

that can be altered and studied (Law, 5). To study the aerodynamics of an aircraft, a small-scale model in a wind tunnel may be sufficient. To study the astrodynamics of a spacecraft, a mathematical model incorporating orbital mechanics may be more valid.

Finally, an analytic solution or simulation solution should be obtained. An analytic solution can be obtained through calculation of the mathematical model.

If not all variables are known or the problem is too complex for an analytic solution, simulation can be employed to numerically exercise the mathematical model (Law, 5). Figure 4 illustrates a series of steps that must be applied in order to have a sound simulation study. A description of these steps is found in Appendix A.



Source: Law, Figure 1.68

Figure 4. Steps in a Simulation Study

The use of modeling and simulation is well established within the DOD community. There are several levels of simulation in the area of combat modeling, as shown in Figure 5. System- or engineering-level models found at the base of the pyramid model the individual characteristics of a system. Engagement-level models attempt to assess a system's performance (e.g., probability of kill) against an adversary system in a "one on one" engagement. Mission-level models are "one vs. many" or "many vs. many" battle models that attempt to measure the operational performance of the system(s). Theater or campaign models attempt to represent the entire military operations of a war including ground, sea, and air components.

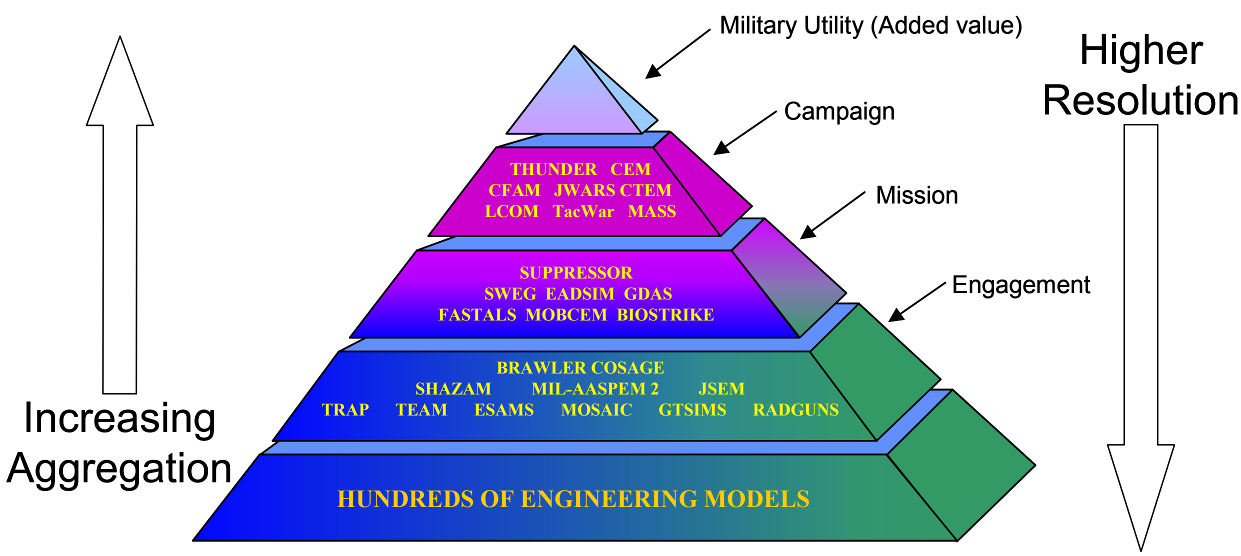


Figure 5. Model Hierarchy

According to Presidential Decision Directive NSC-49, modeling is the approved method to demonstrate the effectiveness of a space system. It will be important to determine how space is currently modeled (PDD-NSC-49/NSTC-8). There are too many models in existence to review in detail in this research. Therefore, the major Theater-level models are reviewed. The first model, the Integrated Theater Engagement Model (ITEM), simulates warfare across a wide spectrum of conflict from the individual unit level to a major regional conflict. The second model, Tactical Warfare (TACWAR), is a Joint model used to simulate 2 sided theater level combat. THUNDER is a stochastic, two-sided, analytical simulation of campaign-level military operations sponsored by the Air Force Studies and Analyses Agency (AFSAA) and currently is the primary Air Force tool for evaluating the contributions of air and space systems (AFMSRR). Strategic and Theater Operations Research Model (STORM) is the replacement to Thunder. The Extended Air Defense Simulation (EADSIM) assesses the effectiveness of Theater Missile Defense (TMD) and air defense systems against the full spectrum of extended air defense threats (SMDC). The final model reviewed is a new model being developed, the Joint Warfare System (JWARS), is based in joint doctrine and will be capable of representing future warfare; and aid in force structure analysis, acquisition analysis, and CINC course of action analysis (JWARS). Table 4 displays how each of these models represent the various space missions within the simulation. In addition, Appendix B provides a review of simulations that model the various Space, Missile Warning, and/or Information Operation functions.

The System Effectiveness Analysis Simulation (SEAS) is an entity-based, time-stepped, stochastic, multimission-level model designed to help evaluate the military

utility of airborne and space-based communications and ISR assets (Rand, 53). This high fidelity model represents the specific mission level requirements of airborne and space based communications and ISR. Target Prioritization for Links & Nodes (TPT-LN) {Formerly SIAM) analyzes information flow on the battlefield to determine effects-based target priorities and information degradation from weapon use. (Aegis). It models a series of networks consisting of sensors and shooters and the paths that connect them. In contrast to the theater level models displayed in Table 4, these high fidelity models represent a specific aspect of space relatively well. Space is not well represented among the theater level models as is evident by Table 4. However, space is well represented in the various system level models listed in Appendix B.

Table 4. Space Power in Theater Level Models

	ITEM	TACWAR	THUNDER
I. Missions A. Functions	**How model represents space**	**How model represents space**	**How model represents space**
I. Force Enhancement			
A. Communications	Not Represented	Perfect connectivity assumed unless otherwise scripted	Implicit, Intra-theater comm. Handled explicitly for IADS and ground forces; implicitly for ATOs and other military comm.
B. Navigation and Positioning		Effects of GPS played through SABSEL Pks for GPS weapons; User scripts GPS problems	Explicit navigation satellites and orbits affect air-to-surface weapon lethality based upon the DOP caused by the number of satellites available. Forecasts of satellite availability schedule affect weaponeering in deliberate ATO planning
C. Intelligence and Surveillance	Emitter and Sensor Types and Sensor coverage area modeled as objects	Assumed perfect unless otherwise scripted	Explicit representation of EO, IR, Radar, and SIGINT collection and dynamic collection planning. Explicit sensor footprint modeled
D. Environmental Monitoring	Not Represented	Not Represented	Weather forecasting affects input via weather forecast file affecting ATO planning. Terrestrial weather explicitly limits space sensors (if appropriate). Space weather (flares, ion storms, etc.) effects captured through satellite blackouts.
E. Warning	Early warning and Ground controlled intercept (EW/CGI) sites provide warning of attacks based on probability of detection		Explicit DSP and SBIR model for detection of TBM events and curing for dynamic tasking of attack operations and launch warnings on airfield operations
F. Mapping	Not Represented		Not Represented
II. Force Application			
A. Ballistic Missile Defense	Terrestrial defenses engage incoming threats	Explicitly defined TBM and active air defenses engage incoming threats	Explicit, Terrestrial defenses engage incoming threats
B. Power Projection	Not Represented	Not Represented	Not Represented
C. Air, Land, and Sea Defense			
III. Space Control			
A. Prevention (Space Surveillance)	Not Represented	Not Represented	Impacts captured through scripted satellite blackouts
B. Protection			
C. Negation			
IV. Space Support			
A. Satellite Control	Not Represented	Not Represented	Satellite pass generation
B. Logistics of Systems			Not Represented
C. Spacelift			Impacts captured through scripted satellite blackouts

Table 4. Space Power in Theater Level Models Continued

	JWARS (replaces TACWAR, THUNDER, CEM, & ITEM)	STORM (THUNDER replacement)	EADSIM
I. Missions A. Functions	**How model represents space**	**How model represents space**	**How model represents space**
I. Force Enhancement			
A. Communications	Not Represented but Satellite communications data input from DISA's NETWARE model	Explicit comm. satellite and orbit representation. Dynamic campaign effects selected based upon comm. resource (orbital & surface) availability and campaign state.	Models each message from generation to transmission and associated delays
B. Navigation and Positioning	Not Represented	Explicit navigation satellites and orbits affect air-to-surface weapon lethality based upon the DOP caused by the number of satellites available. Forecasts of satellite availability schedule affect weaponeering in deliberate ATO planning	Not Represented
C. Intelligence and Surveillance	ISR sensors are user-selectable for any combination of platform and sensor types. Three platform types exist, EO/IR, Radar, & SIGINT	Explicit representation of EO, IR, Radar, and SIGINT collection and dynamic collection planning. Explicit sensor footprint modeled	Explicit satellites, aircraft and ground units provide surveillance and intelligence data to offensive and defensive units to engage threats
D. Environmental Monitoring	Space Environment not represented, terrestrial weather is modeled but not based on space system provided data	Weather forecasting affects input via weather forecast file affecting ATO planning. Terrestrial weather explicitly limits space sensors (if appropriate). Space weather (flares, ion storms, etc.) effects captured through satellite blackouts.	Not Represented
E. Warning	Not Represented	Explicit DSP and SBIR model for detection of TBM events and curing for dynamic tasking of attack operations	Warning information provided to defensive, offensive, and reconnaissance forces to engage threats
F. Mapping	Not Represented	Not Represented	Not Represented
II. Force Application			
A. Ballistic Missile Defense	DSP modeled as independent satellite detection, weather effects sensors uniformly, regardless of location	Space-to-surface capability is captured through scripting of interactions	Ground, Air, and spaced-based units target and engage threat missiles
B. Power Projection	Not Represented	Not Represented	Not Represented
C. Air, Land, and Sea Defense			Space-based intelligence assets target and engage TBM launchers (TELs)
III. Space Control			
A. Prevention (Space Surveillance)	Not Represented (Damage or destruction of ground stations is modeled)	Impacts captured through scripted satellite blackouts	Not Represented
B. Protection		Not Represented	
C. Negation			
IV. Space Support			
A. Satellite Control	Satellite available or not available	Not Represented	Not Represented
B. Logistics of Systems	Not Represented		
C. Spacelift	Launch is not modeled but space vehicles can be added in time-phased manner	Impacts captured through scripted satellite blackouts	

Source: Modified from ***Payne, 2-10 to 2-13***

What is lacking is an understanding of how to aggregate these system level models represented in Appendix B into relevant theater and global level effects for use in lower fidelity models. Figure 6 visually portrays this lack of intermediate level of representation of space in modeling. A way of organizing the relevant mission details and effects of a space system into several levels of fidelity is required.

Modeling Level	Fidelity	MOE
Global	Low	Non-existent
Campaign		
Theater	Requires Aggregation	
Mission		
System	High	Well defined

Figure 6. Fidelity Issues in Space Modeling

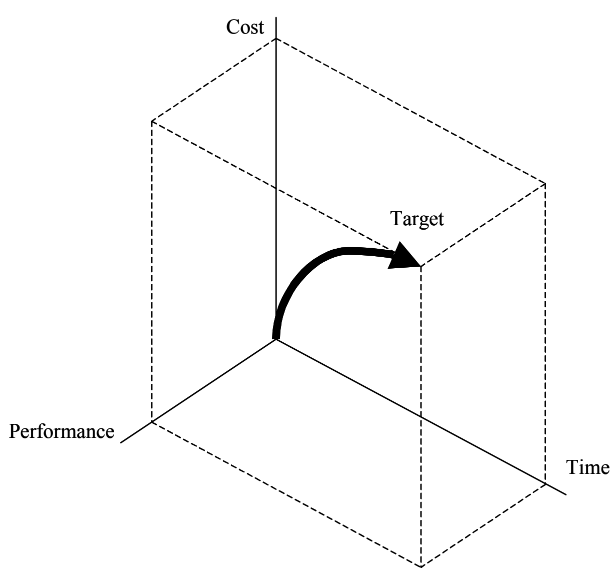
GPS Interference and Navigation Tool (GIANT)

"GIANT is a one versus many constructive and repeatable simulation used to determine GPS and Inertial Navigation System (INS) performance and weapon system operational effectiveness as a function thereof in a GPS interference environment" (Veridian, 1). GIANT was conceived and developed for the GPS Joint Program Office Navwar Program (Veridian, 5). GIANT is controlled and operated by the Space and Missile Systems Center at Los Angeles AFB, California. GIANT is capable of representing air and ground vehicles with or without weapons. Both the launcher and the weapon have GPS/INS navigation systems and the launcher to weapon handoff event is modeled (Veridian, 3). As an option, any number probability of kill is thus traceable to the weapon and the launcher (McLagan, 5). GIANT is a validated and accredited model

and is included in the Air Force Systems Analysis Toolkit (AFSAT).of stationary or moving GPS jammers can be present. Target miss distance and

Project Management

Project Management is a process in which a structured, detailed planning, and implementation strategy is incorporated for obtaining an organization goal or goals (Nicholas, 19). The U.S. military uses project management in the acquisition process of new systems. "It (Project Management) is often associated with early missile and space programs of the 1960s" (Nicholas, 24). In procuring or developing a new system there are many different processes that are taking place. Managers must employ a strategy to control the performance of a diverse group of people and skills required in order to complete a project on time and within an allotted budget (Milton, 15-19). This is displayed in a relatively simple graph in Figure 7.



Source: Rosenau, 16

Figure 7. Three dimensions of project goals

Project management attempts to organize activities into five functions of management: Planning, Organizing, Leadership, Control, and Change. "The practice of project management pays attention to goal-oriented systems, subsystems, their relationships, and environment; this is what makes project management a systems approach to management" (Nicholas, 21). The planning function focuses on "setting organizational goals and establishing means for achieving them consistent with available resources and forces in the environment" (Nicholas, 19). In other words, the planning process establishes "what needs to be done, how it has to be done, by whom, in what order, for how much, and by when" (Nicholas, 160).

The Organizing function deals with three areas of responsibility. The first is to train and manage personnel into a system of authority, responsibility, and accountability. The second is to acquire and allocate facilities, materials, and capital. The final responsibility is to organize the above into a suitable structure that includes policies procedures, and communication channels (Nicholas, 19).

Leadership involves the direction and motivation of personnel to obtain organizational goals. For most leaders, the influencing of individual or group performance is a primary concern (Nicholas, 20).

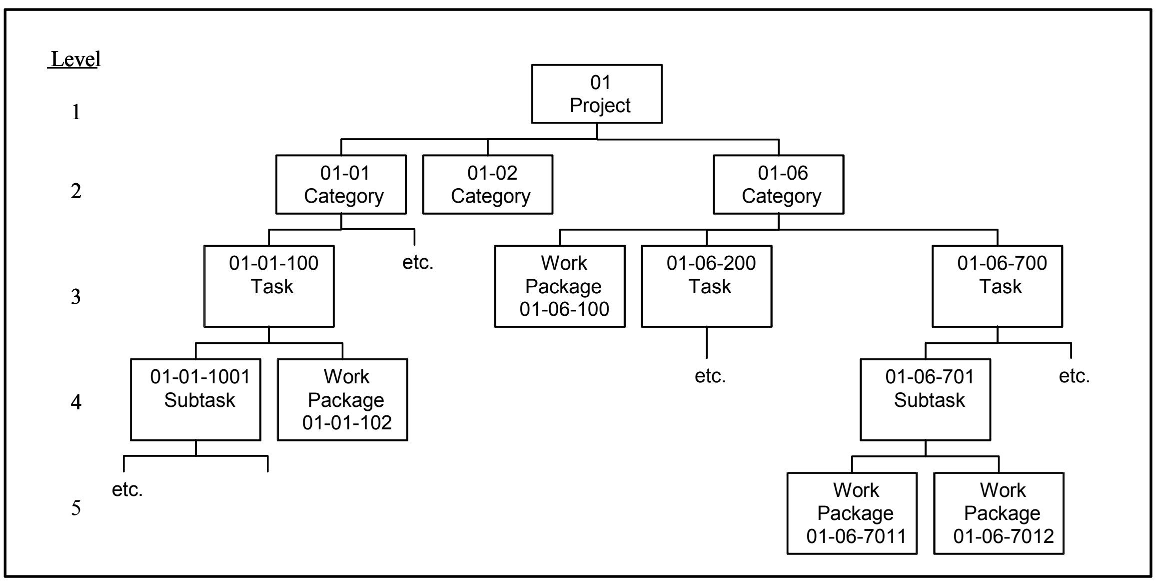
Control represents the quality of the project. Performance measures of effectiveness or efficiency are assessed and any corrective action is taken (Nicholas, 20).

Change simply encapsulates the dynamics involved in any major project. Change can affect project schedules, goals, timetables, and/or responsibilities.

Within the Planning phase, an array of tools is used to help organize the work, responsibilities, and goals within the project. These tools include: Work Breakdown

Structure (WBS), the Responsibility Matrix, Key Events and Milestones, Gantt Charts, networks, decision analysis, critical path analysis, cost estimating, budgeting, and forecasting.

The purpose of the WBS is to "reduce the project into work elements that are so clearly defined that they, individually, can be thoroughly and accurately defined, budgeted, scheduled, and controlled" (Nicholas, 165). The level of breakdown is dependent on the project and varies between projects. Figure 8 depicts the hierarchical elements of a WBS (Nicholas, Figure 6-1, 166). These elements are broken down into manageable pieces called work packages (Nicholas, 165). The level of decomposition is not fixed and is dependent on the project definition and requirements.

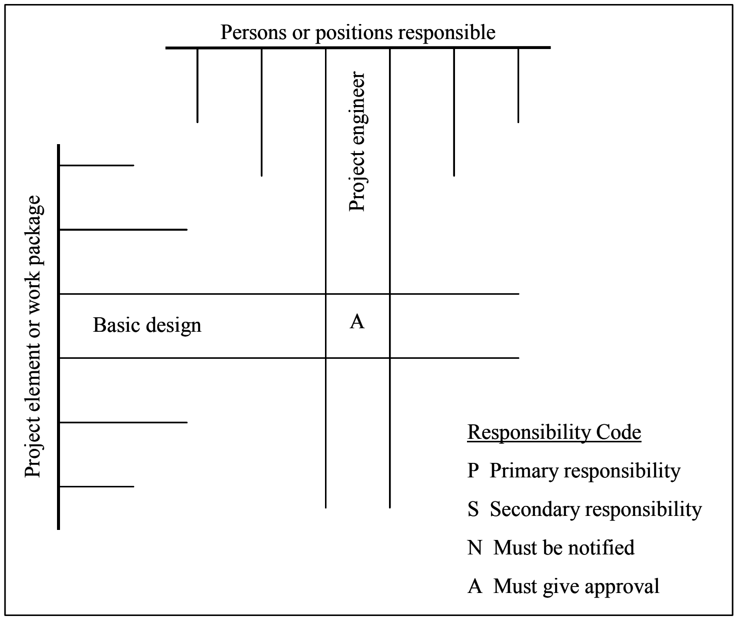


Source: Nicholas, 166

Figure 8. WBS Elements

The WBS organizes what needs to be done. By combining the WBS with a structured organization chart the responsibility matrix is created (Nicholas, 175). This

matrix or chart allows the management of work packages and by assigning responsibility in an effective manner. Figure 9 depicts a simple responsibility matrix consisting of a single work package and functional position (Nicholas, Figure 6-7, 175).



Source: Nicholas, 175

Figure 9. Simple Responsibility Matrix

The responsibility matrix not only shows the level of the organization that is responsible for a function, it also shows *who or what* will be impacted by a change in a work package design or schedule. The matrix, combined with other tools, allows the project manager to track effects of various changes in work packages on other work packages, which may or may not be under the direct control of the manager of the work package undergoing a plan change. Tracking these primary and secondary effects is critical to identifying effects and benefits.

Global Positioning System

The Global Positioning System (GPS) is a system nominally consisting of 24 military satellites that provide continues global positioning, navigation and timing information (SMC, 1). These satellites transmit a signal that can be processed by a receiver that then computes position, velocity, and time within an amount of error.

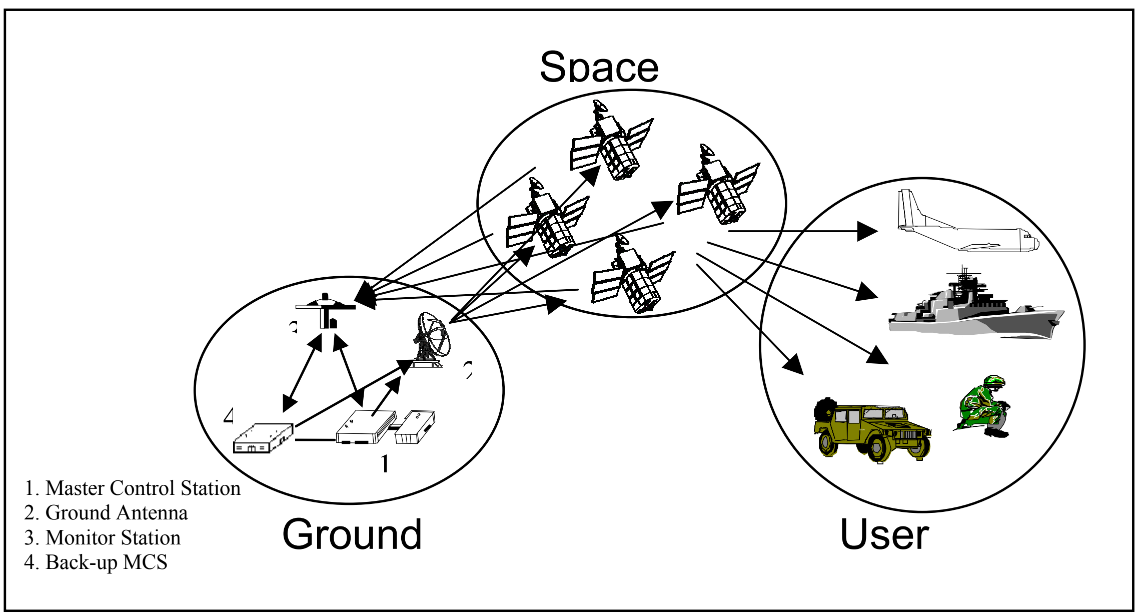
The error is caused by several factors. The space and atmospheric environments account for most of the errors in GPS positioning since Selective Availability (SA) was discontinued. SA is the intentional degradation incorporated into the civilian signal by the military. SA was discontinued due to increasing civilian demand for more accurate positioning and navigation information.

GPS provides two separate signal codes, the Precise Positioning Service (PPS) and the Standard Positioning Service (SPS) (NAVSTAR, 1). The SPS signal communicates on the C/A (Coarse Acquisition) code while the PPS signal communicates on the P(Y) (Precise (encrypted) code. Table 5 details the PPS and SPS accuracy indicated in the 1999 Federal Radionavigation Plan and the SPS Signal Specification document.

Table 5. GPS Accuracy

	SPS (SA off)	SPS (SA on)	PPS (Worst Case)	1999 FRP PPS (CJCS)
Horizontal Error	≤ 13 meters (SIS only)	≤ 100 meters (SIS only)	≤ 6.3 meters	≤ 22 meters (17.8 meters)
Vertical Error	≤ 22 meters (SIS only)	≤ 156 meters (SIS only)	≤ 13.6 meters	≤ 27.7 meters
Time Transfer Error	40 Nanoseconds	340 Nanoseconds	20 Nanoseconds	100 Nanoseconds
All statistics at 95% Confidence Interval: Actual position will be within the error listed above 95% of the time.				
Sources: 1999 FRP, C-6; GPS SPS Signal Specifics, 15; NAVSTAR, 1; Chairmen, D-3; HQ AFSPC, 3-17				

The GPS is composed of three segments; a space segment (space vehicle(s)), a control segment (ground stations) and a user segment (personnel or systems in the field) (HQ AFSPC, 3, 1). The control segment consists of five Monitor Stations located in Hawaii, Kwajalein, Ascension Island, Diego Garcia and Colorado Springs (NAVSTAR, 2). There are three ground antennas also located at Ascension Island, Diego Garcia, and Kwajalien (NAVSTAR, 3). The Master Control Station (MCS) is located at Schriever AFB. The monitor stations track all satellites in view, accumulate and process ranging data to determine satellite orbits and to update each satellite's navigation message (Dias, 3). This updated information is then transmitted to each satellite via the Ground Antennas. User segments then receiver position, velocity, and time information from the space segment. Figure 10 depicts the interaction between these segments.



Source: HQ AFSPC, Figure 3-1

Figure 10. The Global Positioning System

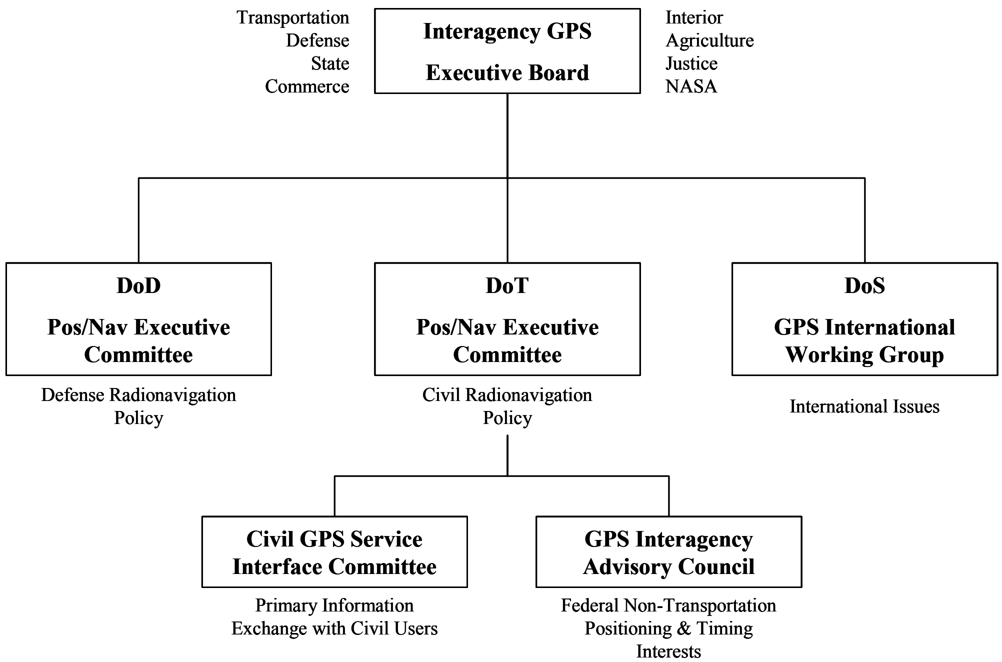
The original purpose for GPS was to aide in the tracking of ballistic missiles. Today, "the primary mission of the GPS is to provide precise, all-weather, three-dimensional position, velocity and time (PVT) information to an unlimited number of properly equipped military and civil users in the air and space and on the land and sea" (HQ AFSPC, 1, 1). An additional mission of the Space Vehicle (SV) the GPS is attached to is to provide national warning of nuclear detonations via the Nuclear Detonation (NUDET) Detection System (NDS) (HQ AFSPC, 1, 1). The NDS is a complementary payload on the GPS bus. However, for this research it is considered a separate system that must be studied in a similar fashion. GPS is used by the military in peacetime and in wartime operations.

> GPS wartime navigation support applications include en route navigation, low level navigation, target acquisition, close air support, missile guidance, command and control, all-weather air drop, sensor emplacement, precision survey, instrument approach, rendezvous, coordinate bombing, unmanned aerial vehicle (UAV) operations, search and rescue, reconnaissance, range instrumentation, and mine emplacement. GPS provides precise time transfer support to the warfighter by synchronizing distributed and diverse battlefield sensors and communications systems. (HQ AFSPC 1, 1)

In addition to the military, civil organizations, foreign organizations, and individuals use the PVT information as well. Civilian and International use of GPS makes GPS unique for a military system, as it is one of the few military system also used by civilian and foreign organizations.

> Civil navigation applications include intercontinental en route navigation, vehicle monitoring, oceanic and coastal navigation, harbor operations, resource exploration, hydrographic and geophysical surveying, position reporting and monitoring, and coordinating search operations. The GPS precise time transfer mission is vital to synchronizing a growing number of distributed civil utilities including electrical, sewage, water and telecommunications. (HQ AFSPC, 1, 2)

GPS is operated by the Department of Defense (DoD) and managed by the Interagency GPS Executive Board (IGEB) (HQ AFSPC, 1, 1). Figure 11 displays the organizational structure of the IGEB (IGEB).

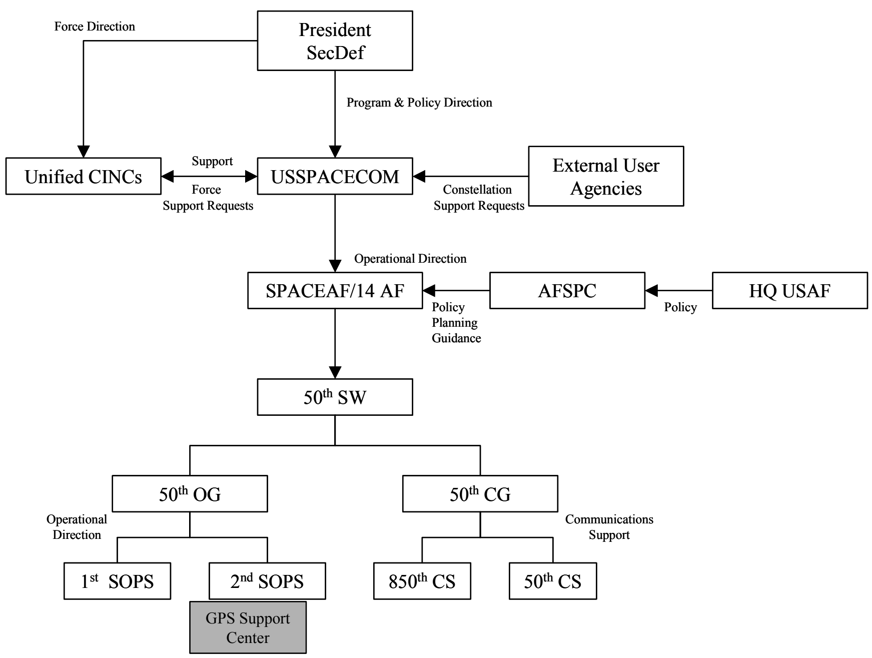


Source: IGEB Web Site

Figure 11. GPS Management Structure

As indicated by Figure 11, the GPS military satellite constellation is managed by an interagency organization that allows representation of the major users of GPS service. As owner, operator, and maintainer of the GPS system, the Department of Defense provides policy direction to USSPACECOM. USSPACECOM provides support to other Unified CINCs and external user agencies via the 14^{th} Air Force and the 50^{th} Space Wing. DoD assigned the GPS Support Center (GSC) as the lone focal point for operational issues and military matters relating to GPS (GSC). Additionally, the GSC is US Space Command's interface to the US Coast Guard's Navigation Center (NAVCEN) and

Federal Aviation Administration's National Operations Control Center (NOCC) (GSC). The NAVCEN represents the Department of Transportation's (DOT) Civil GPS Service Interface Committee depicted in Figure 11. This relationship structure is depicted in Figure 12.



Source: HQ AFSPC, 2, 3

Figure 12. GPS Command Organization Structure

The 1st Space Operations Squadron provides GPS support during launch, Low Earth Orbit (LEO) transfer, and disposal phases (HQ AFSPC, 2, 4). The GSC and the 2nd Space Operations Squadron are responsible for day-to-day command and control, space segment maintenance, anomaly resolution, navigation and time transfer, nuclear detonation detection missions of the GPS satellite constellation, and space support to warfighters through GPS Performance Prediction and Mission Planning, and GPS Enhanced Theater Support (HQ AFSPC, 2, 4). The GCS also interacts with the civil users of GPS.

III. MODELING AND ANALYSIS

Introduction

Air Force Space Command (AFSPC) requires a methodology to consider modeling and measuring the military space. As the military services become increasingly dependent on civil and commercial space systems for mission planning and situational awareness of the battlefield, a methodology needs to be developed and understood (AFDD 2-2, 14). Figure 13 outlines the proposed framework to aid in the determination of the military worth of space and is further discussed in greater detail.

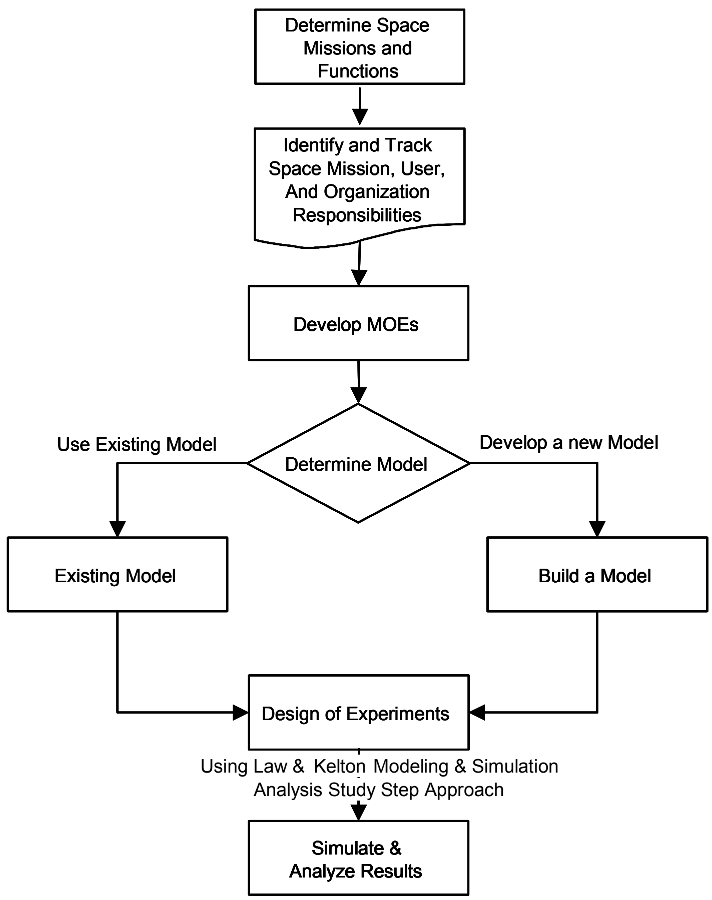


Figure 13. Proposed Methodology

Determination of Space Mission

The first step in determining the modeling of military space is to understand what Space provides to military operations. This includes long-term and short-term impacts space has on the warfighter and basic military operations during peacetime and in wartime. Understanding what support, information, and functions a single space system provides in every phase of operations is fundamental to modeling its use and effectiveness. This information can be found in relevant Joint and Service level doctrine, and Concept of Operations (CONOPS) documents. Research from service schools (Air Command and Staff Collage, Air War College) and academic institutions can be invaluable sources of information, highlighting the future of space missions. Doctrine is essential for the determination of military effectiveness as mentioned in Chapter II. In addition to specific doctrine, system experts, system users, System Program Offices, and senior leadership guidance are areas for information of space system missions.

Each space system has a primary mission (or missions) for which it was built. After a system is commissioned, secondary and tertiary missions are added as new uses for a space system are discovered. These ancillary uses, while not initially intended when the system was designed, must be considered when modeling the military system.

In order to capture the primary and ancillary missions of a space system a mission organization format is required. The work breakdown structure (WBS), adapted from project management, can be used to capture the interactions of a space system. The mission of each of the space system segments may be viewed through a modified WBS; a mission breakdown structure (MBS). This structure is similar to an organization chart listing all the appropriate mission functions relating to the space system of interest.

Ideally, every principle or material mission must be captured in this process in order to model the space systems. Unfortunately, this might not be realistic as this process is extremely time consuming and space systems are used at an increasing rate. Clearly, critical missions must be identified and understood. Once these missions have been identified, it becomes easier to highlight any interactions that exist between other systems and users and what is required to be modeled. It is these interactions that help determine the military effectiveness of the space system. It is a recommendation of this study that such information be tracked and provided in a multiple classification level database. Such data will ease the modeling of space assets and activities.

Tracking of Space Mission Users

The next step in the framework is to identify and track the various long-term and short-term key users or user classes of the space systems using the MBS as a guide. Again, due to the sheer volume of users, this may not be a realistic goal at the high fidelity level. Identification of the effects of the space system on critical users is necessary. Adapting the responsibility matrix from project management will allow AFSPC to identify and track the critical and secondary users and missions a space system supports. As the primary and ancillary missions grow, new users classes can be identified and tracked, highlighting areas for continued study. By tracking both space system missions and its users, an understanding of how space affects military operations will be gained. By representing the interactions in an organized and thorough manner, assessment of military effectiveness can be studied. This may help to identify important interactions that can be further investigated. Recall that the military may not be the only

user of a particular space system. Civilians, corporations, and many foreign countries use the information provided by several U.S. space systems, not just the GPS example given in Chapter I. The reliance on this information infrastructure by civilian institutions and corporations is also important in determining military worth. The U.S. Military exists to defend the United States and its people, which include its civilian infrastructure. When considering the military worth of space, it may be relevant to measure the military worth of civilian space systems and civilian use of military systems as well. Such information should be organized into a database and kept up to date. As missions are added or deleted, the mission breakdown structure with the primary and ancillary effects should be tracked or examined inside the responsibility matrix. Any modeling and measurement of military space will gain the knowledge of these interaction affects. Of course, as with all modeling, it will be necessary to identify the key "drivers' for the analysis under consideration.

Develop Measures of Effectiveness

Classic Measures of Effectiveness (MOE) exist for most weapon systems in use for military operations. Given increases in technology do these measures provide enough insight into the interactions that they are meant to capture or are new measurements needed? What is an appropriate measure for a space system, which provides simultaneous global support to military and civilian users? What about long-term versus short-term effects? These are difficult questions to answer and highlight the difficulty in evaluating space systems. Surveying space-based information users to find out exactly how space is used in completion of their mission aids in the development of appropriate

measures of effectiveness. Another factor to consider is level of fidelity. Classic MOE, such as P_k, are great at measuring high fidelity effects but what is lacking is lower fidelity MOE that represents similar measures at an aggregate level. The development of proper MOE's for the level of fidelity required is a critical modeling and analysis issue.

Modeling

The next step in this framework is to demonstrate the worth of the space system of interest using a representative model. As discussed in Chapter II, space is not well represented above the system level in modeling and simulation. A reason for this is the difficulty of aggregating the effects of space-based systems. The global influence provided by space systems are currently measured only in local terms as represented in system level models. This high fidelity modeling may not be appropriate for low fidelity issues. A means of aggregating these high fidelity models into lower levels of fidelity is needed.

First, armed with the necessary space system mission details and appropriate MOE, an inspection can be performed of the current existing models available for analysis. If a model exists that is suitable as a surrogate for the space system of interest and is capable of providing the appropriate level of detail then it should be used. However, if a model does not exist, it needs to be built. The modeling process itself is a complex and difficult process and it is beneficial to use well-accepted techniques for successful modeling. The recommended process for using modeling and simulation was listed in Chapter II, Figure 4 (see Appendix A). A model does not need to be extremely complex to be valid—simplicity is sometimes preferred (Ravindran, 3). To capture some

of the effects of space, this intermediate step of modeling just the appropriate effects, is an option to consider.

Space, while a complex environment, should only be modeled with the features that are relevant. Unneeded complexity can be eliminated using the responsibility matrix to further define the questions and problems to be modeled. The responsibility matrix allows an analyst or decision maker to track the effects of changes in work packages on the overall schedule as well as its effect on other work packages. In this case, the responsibility matrix allows space operators to track the effects of changes in the primary and ancillary missions of a space system, other systems and the users of the space systems.

A complete up to date inventory of models and how space interacts in them is required. A flexible plug and play simulation environment to measure effects and a Verified, Validated, and Accredited model of both space and war that captures multiple effects – primary, secondary, tertiary, and allows for short term and long term effects.

Design of Experiments

Once the primary and ancillary missions of a space system are understood and a full identification of military operations utilizing military or civilian space-based information is accomplished, an appropriate Design of Experiments (DOE) needs to be defined in order to test the worth of a space system in regards to the issue at hand. A DOE is necessary to properly control and evaluate any experimentation. The information provided by the responsibility matrix allows us to make certain characterizations about the system of interest that can then be tested using a design of experiments. "In most

real-life situations the experiment must be done under one or more constraints…Often a trade-off must be sought between quality of information obtained and the time (or cost) required to obtain it" (Murthy, 195). As previously mentioned, the level of information required to determine the total effectiveness of a system may be unobtainable or require too much time to collect to address the question in time for the issue at hand. The long-term and short-term effects global space systems provide to military operations may be successfully modeled, but only after characterizations can be made and tested by appropriate design of experiments. Questions and hypotheses should be developed about the space system of interest and the various missions enabled by space. The appropriate information and design of experiments should attempt to answer the questions about the space system. AFSPC has provided some examples of questions they are interested in answering.

- What synergistic effects do satellites provide to mission accomplishment and how are these force multipliers measured?
- [How] Does the loss or degradation of space assets affect putting bombs on target?
- How do we measure damage or degradation in satellite?
- At what point does satellite degradation start affecting mission effectiveness?
- At what points in the peace, pre-conflict, conflict, return to peace process is space critical? (Whitsel, 2001)

Once characterizations about a space system can be made and appropriate measures have been selected appropriate analysis can be accomplished to determine its military effectiveness.

As space systems often provide multiple primary and ancillary missions, ideally each *material* mission would be evaluated in regard to the question at hand. If such a review is infeasible, then critical missions must be reviewed. Each mission may have different measures of effectiveness and a different population of users at various levels of aggregation. In order to measure the total effect of a space system, mission studies may have to be aggregated. The main task will be identifying and quantifying key "drivers" of military worth and then aggregating this information to an appropriate level of fidelity.

Simulation and Analysis

Analysis of the results of the modeled space system should be accomplished using the predefined experiment and valid statistical or analytical techniques. Due to the wide range of space systems and mission uses, one technique may be preferable to another; therefore any one technique is not recommended in this methodology. Instead, insistence on the importance of valid analysis at the end of the study is required.

As a pilot example, the effectiveness of the GPS positioning data and its affect on munitions accuracy will be modeled using GIANT in Chapter IV. The error associated with GPS positioning, both for an airframe and a particular munitions, will be the subject of this pilot study. Of particular interest, is how degradation of the GPS signal affects the positioning error of both the GPS-guided launching airframe and the GPS-guided weapon system? DOE will be used to determine significant interaction of these errors and their effect on weapon lethality.

IV. RESULTS AND ANALYSIS

Overview

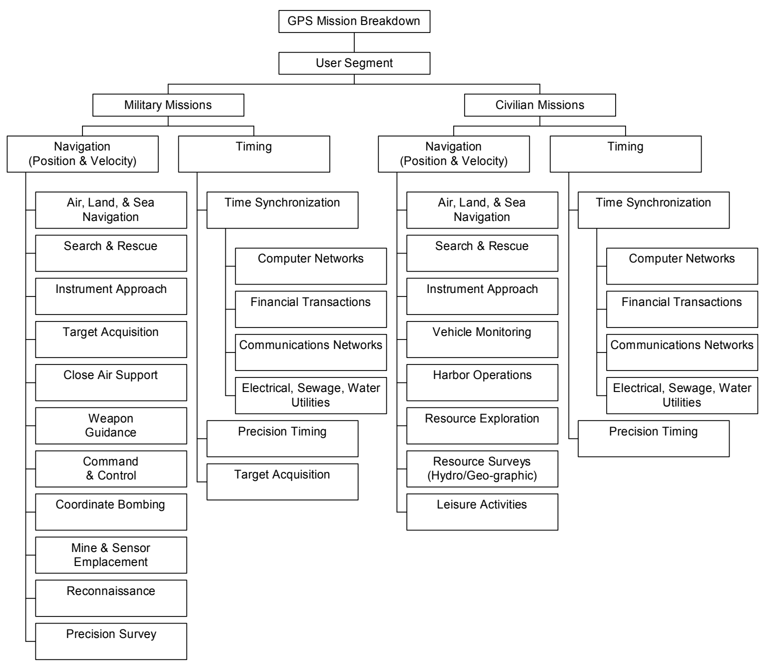
The approach proposed in this thesis is applied to a pilot study of a facet of the Global Positioning System (GPS) to illustrate the military effectiveness of the GPS. While this approach will not capture all primary and secondary effects of GPS, it will illustrate how data can be developed and tested for this purpose. This study will focus on how the degradation or denial of a GPS signal affects a GPS-guided weapon. To carry out a complete analysis of GPS, an aggregation of critical missions must be analyzed in a similar fashion.

It should be noted, however, that to completely assess the military worth of GPS, this process must be applied to all key aspects of the GPS mission (both short-term and long-term), not just the single example provided here. Resources (time limitations, as well as classification restrictions) have precluded such a complete analysis. The illustrative example is provided not to completely evaluate the worth of GPS, but rather to illustrate the concept.

Mission Breakdown Structure

The GPS mission, as represented in AFSPC's *GPS Concept of Operations (GPS CONOPS)* document, is to provide precise, all-weather, three-dimensional position, velocity, and time (PVT) information to military and civil users in air, land, sea, or space environments during peacetime and wartime operations. GPS uses in times of war include: enroute navigation, low-level navigation, target acquisition, close air support,

missile guidance, command and control, all-weather air drop, sensor emplacement, precision survey, precision timing, instrument approach, rendezvous, coordinate bombing, UAV/UCAV operations, search and rescue, intelligence gathering, and time transfer. Additional wartime uses of GPS would include the same civil uses that are carried out in times of peace. GPS fulfills a mission support or force enhancement role. These roles are depicted in Figure 14. This chart, listing the mission functions provided by GPS, was created from unclassified and open-source literature.

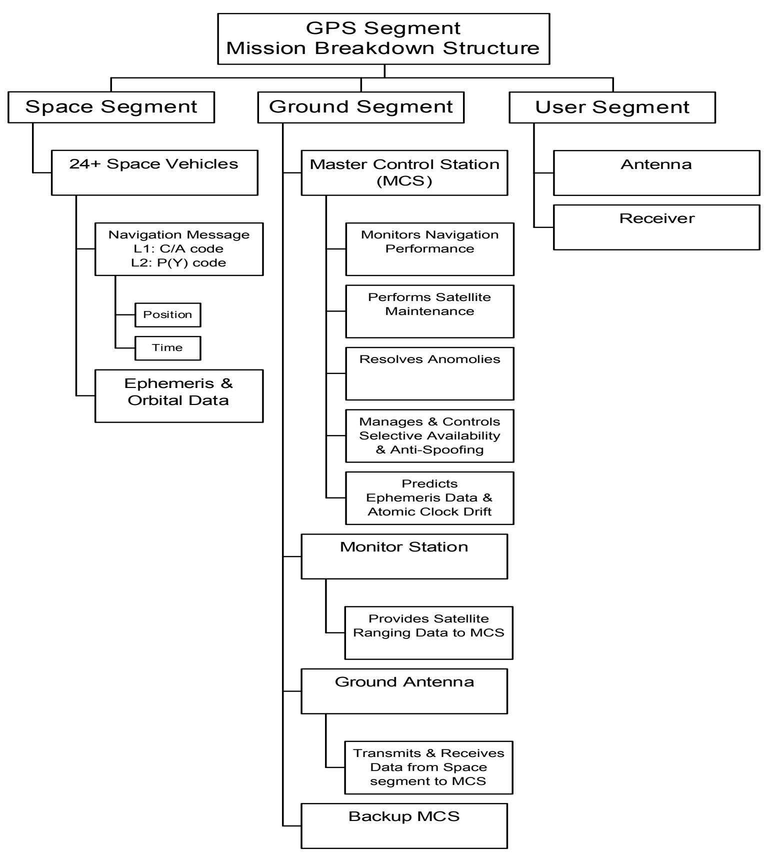


Source: Open-source literature

Figure 14. GPS Supported User Segment Mission Breakdown Structure

Figure 15 depicts the mission of each segment in the GPS. The space segment provides the navigation and timing information used by military, civilian, and commercial sectors. The ground segment provides command and control, prediction, and

maintenance of the satellite and navigation message. The user segment only receives and processes data for mission use. For example, an F-15E GPS and Inertial Navigation System (INS) guidance system or JDAM guidance package would fall under the user segment. This chart was created from unclassified open-source literature. The secondary GPS bus payload, the NUDET Detection System is not modeled within this research. As a separate system, NDS must be similarly studied, but its interaction would be key in capturing the total worth. In addition, in a larger study, all the other key military and civilian uses ("drivers") must be studied to adequately model the "worth" of GPS.



Source: Open-source literature

Figure 15. GPS Segment Mission Breakdown Structure

Responsibility Matrix

The responsibility matrix aids in understanding of the various interactions of the GPS missions and the responsible organizations. Ideally, such matrices would be created electronically and be maintained by the relevant organizations. Web-based, interoperable model architecture will be required to organize such a database. Multi-level classifications will also be needed if military and civilian users have access to this database. To create the responsibility matrix, the mission breakdown structures are cross-referenced with the GPS organizational command structure found in AFSPC's GPS Concept of Operations document. A limited responsibility matrix is displayed in Figure 16. This chart gives a simple example for various types of platform. For example, the F-15E airframe uses GPS Positioning and Velocity (Navigation) information for Navigation as well as Timing data for information and data transfer to the on board weapons systems.

As mentioned in the previous chapters the responsibility matrix allows for the tracking of effects on the mission caused by changes in the availability of the GPS navigation and time message. Changes in timing or navigation information would have limited effect on a civilian luxury sedan with onboard GPS navigation. The driver would still be able to navigate provided they know the route or had a map. However, changes in the positioning and timing information could have a serious effect on the Navy's high-tech AEGIS Class Destroyers. Changes in positioning data can also affect air platforms and weapons delivery. The F-15E can deliver gravity bombs, which do not require GPS information, however, changes in GPS information can affect the position of the F-15E at weapons release, which indirectly transfers the position error to the gravity bomb.

GPS Mission Breakdown Structure	GPS User Segment						
	Miltary Uses					Civil Uses	
	Air Platforms F-15E GPS/INS	Land Platforms M-1A2 ABRAMS	Sea Platforms AGIS Class Destroyer	Weapon Systems Mk-84 JDAM	Air Platforms Boeing 777 GPS/INS	Land Platforms Mercedes GPS Navigation	Sea Platforms Exxon Valdez
Space Segment							
Navigation Message							
Ephemeris & Clock Data							
Ground Segment							
Navigation Performance							
Satellite Maintenance							
Anomaly Resolution							
Selective Availability							
Anti-Spoofing							
Ephemeris & Clock Prediction							
User Segment							
Positioning	X	X	X	X	X	X	X
Velocity	X	X	X	X	X	X	X
Timing	X	X	X	X	X		

Source: Open-source literature

Figure 16. Limited GPS Responsibility Matrix

Measures of Effectiveness

The literature review provided the relevant unclassified information to illustrate the mission breakdown structure (MBS) and responsibility matrix for the use of GPS-provided navigation information in an operational short-term wartime environment. This mission organization process was then used to aid in the determination of the military worth of GPS in an operational mission setting using the appropriate measures of effectiveness (MOE). The MOEs chosen for this pilot analysis were the circular error probable (CEP), horizontal 1-sigma error, and P_k. CEP is the radius of a circle centered at the true target location of which a certain percentage (i) of measured impacts fall. CEP is used for horizontal accuracy using the following formula at various levels of confidence is:

$$CEP_i = \sigma\sqrt{-2\ln(1-i)}$$

where i is the level of confidence desired and σ is the horizontal 1-sigma error (GIANT, Veridian). These are classic measures that are commonly accepted by the operator community and used in the Joint Munition Effectiveness Manuals (JMEMs) to assess weapon effectiveness.

GIANT Scenario

As an illustrative example of one aspect of the type of analysis that must be undertaken, the operational wartime mission of GPS is modeled in GIANT. To determine the effects GPS has on an operational mission, GIANT was used to model the flight route of a Joint Directed Attack Munitions (JDAM) weapon and the F-15E airframe. Due to its extensive usage during the prosecution of the war on terrorists in Afghanistan and its subsequent procurement increases, Joint Directed Attack Munitions (JDAM) was selected as the specific weapon to be modeled. To model JDAM accuracy, an adequate launch platform is required. The F-15E was chosen for a launch platform because it was readily available within the model selected for analysis.

There are three major sources of GPS related error for the weapon. The first would be the initial GPS-derived position and velocity error provided by the launching platform, in this case the F-15E. A second source of error derives from the GPS-based guidance and control systems on the JDAM itself. A final source of error derives from the geometry of the GPS constellation relative to the user, which varies with time.

The primary focus of this pilot research is on the overall accuracy of the weapon system. The F-15E platform is only modeled to develop the initial position and velocity

error associated with weapons release, which is a result of the F-15E's GPS/INS drift error. Ideally, an appropriate random process would represent the drift error; however, the F-15E guidance system drift error is classified. While this data could be illustrated with a uniform or triangular distribution, it would be more precise to use the actual drift. For the purpose of this illustration such classified numbers were unnecessary. Further, the drift error is dependent on whether or not GPS is available. If GPS were available, then the guidance accuracy would be within 6.3 meters or less as listed in HQ AFSPC *GPS Concept of Operations*. If GPS were not available, then the drift error will grow no greater than 0.8 nautical miles per second as specified by Litton's guidance and control system (LN-94 Second Generation F-15 INU) for the F-15E (Litton).

A final potential source of error is enemy jamming of the GPS signal. Jamming degrades the GPS signal strength, making it more difficult for GPS receivers to acquire the GPS signal. These Jammers come in a variety of sizes and power outputs from a 1-watt hand-portable jammer to a 1000-watt vehicle-mounted jammer (Veridian). Due to classification issues and the large variety of existing jammers, jammers werel not specifically modeled. As a surrogate, the GPS signal strength itself will be degraded. Degradation can occur from space environmental weather, atmospheric conditions and signal jamming. A jammer has the effect of reducing GPS signal strength so directly modifying the signal strength will have a similar effect. If this scenario were expanded beyond this limited example, local GPS jammers would need to be modeled.

Several input factors must be considered before a valid scenario can be simulated. Veridian Engineering of Dayton, Ohio supplied the GIANT model and some notional input data. In addition, the Naval Air Warfare Weapons Division (NAWCWPNS),

GPS/INS Branch provided ephemeris data for *GPS Week* 129, 13-19 February 2002. This data is used to determine position and velocity of the GPS satellites over the specified time period. Table 6 provides the relevant data chosen as input into the GIANT scenario.

Table 6. GIANT Scenario Input Data

Model Input	Data Used	Remarks	File Name
SV Signal	28 MHz on L1 C/A, 10 % increments 25 MHz on L1 P(Y) 22 MHz on L2 P(Y)		Satellitethesis.SIG
MEO Constellation	Week 129 ephemeris data	Provided by Naval Air Warfare Weapons Division (NAWCWPNS)	New_Week0129.MEO
UERE	Not user created, supplied with model	Supplied by Veridian	
Terrain	North East Asia Terrain	Supplied by Veridian	NEA.TER
SSPD	JDAM P_k calculations based on target CEP	Supplied by Veridian	Wpn012-Tgt0001.SSPD
Munition	**Circular Error Sigma** Target Location: 6 Meters Weapon Guidance: 2 Meters	Supplied by Veridian	JDAM.MUN
Body Masking	F-15 & JDAM Body Mask Files	Supplied by Veridian	F-15 & JDAM. Body
GPS Antenna	GAS7 ANEFS for F-15 Generic FRPA for JDAMs	Supplied by Veridian	GAS7.ANEFS Installed.FRPA
GPS Receiver	GemIII receiver for F-15 JDAM receiver for JDAM	Supplied by Veridian	GEMIII.REC JDAM.REC
Inertial Navigation System (INS)	EGI F-15 INS JDAM INS	Supplied by Veridian	EGI.INS JDAM.INS
Platform	F-15E Launcher Platform JDAM-Mk84 Weapon Platform	Supplied by Veridian	F-15E.PTF JDAM.PTF
Target Laydown	Lat: 38.666, Long: 125.8333		Thesis.TGT
Control	Initial Ephemeris time 3600 seconds		Thesis.CASE
Routes	Route #1 is Launcher Route Route #2 is Weapon Route		Thesis.ROUTELIST
Attrition	Zero attrition applied, no threats modeled	EADSIM data can be input for platform attrition	Thesis.ATTR.GNT
Target Weapon Allocation	1 weapon per attack and 1 weapon per target		Thesis.DMPI.GNT
Hand-off	Random Distribution	Random Distribution for Initial Position Error	Thesis.HANDOFF

Source: Veridian, GIANT Users Manual, GIANT Analysts Manual

Design of Experiments

The signal strength of the L1 C/A frequency was degraded by 10 percent increments to 50 percent. This was sufficient for simulating various jammers of increasing signal strength. Table 7 presents this design of experiments (DOE) graphically. The factors in this pilot study will then be tested for differences in the mean at the $\alpha = 0.05$ level.

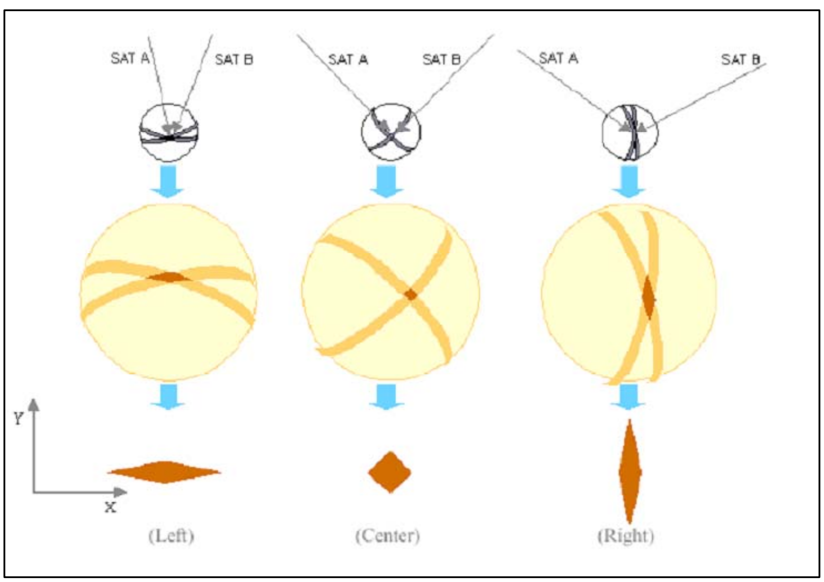
Table 7. Design of Experiment

2-Factors	6-Levels
Initial Degradation	No Initial degrade
	10% Initial Degrade
	20% Initial Degrade
	30% Initial Degrade
	40% Initial Degrade
	50% Initial Degrade
Degrade After Weapons Release	No Degrade After Release
	10% Degrade After Release
	20% Degrade After Release
	30% Degrade After Release
	40% Degrade After Release
	50% Degrade After Release

The formal hypothesis test used during this process uses the "paired observation" approach mentioned in Hartman's *High Resolution Combat Modeling*. "Let Z_i be output MOE from n_1 independent replications of *scenario* 1 and let Y_i be the same MOE from the n_2 independent replications of *scenario* 2. If $n_1 = n_2$, then the paired observation approach can be used" (Hartman, 2-28). $X_i = Z_i = Y_i$ for $i = 1, 2, \ldots, 30$. For large X_i, scenario 1 was better, for small X_i, the scenarios were about the same. The confidence interval for population means, $CI = \overline{X} \pm t(n-1, 1-\alpha/2)\sqrt{S^2/n}$, can be used to gain information on the differences in scenarios. If the CI contains zero then there is no significant difference between the two scenarios. A CI greater than zero it implies scenario 1 is better. A CI of less than zero implies scenario 2 is better. This approach is

used for every confidence interval except when sample sizes are not the same. Means comparison for different sample sizes is used in this case.

GIANT was used to model the drift error and subsequent initial weapon release error. Using the F-15E as a launching platform, a bombing route was simulated with 30 replications. Each replication start time was increased by one hour to account for normal fluctuations in daily Dilution of Precision (DOP) error. DOP is the normal fluctuation in GPS position error due to satellite placement in the sky. If the satellites are too low or too high in the horizon, GPS error coverage area increases in size. This is displayed in Figure 17. For minimum GPS error (lowest DOP) a user needs one satellite directly overhead and three spaced about 120-degrees apart near the user's horizon. As the GPS satellites move in their orbits throughout the day, changes to DOP are expected.



Source: GPS SPS, 2.1.2-1

Figure 17. GPS Dilution of Precision

Results

During the simulation, GIANT creates a weapon handoff file that contains the horizontal and vertical position, velocity, and time errors associated with a weapons release. The horizontal error measured by GIANT is the difference between the Desired Mean Point of Impact (DMPI) and the actual impact point. This is referred to in GIANT as the Horizontal 1-Sigma error. Table 8 displays the resulting 95% confidence interval about the mean horizontal 1-sigma error.

Table 8. 95% Confidence Interval for the Mean Horizontal Error

Scenario	Average	Standard Deviation	95% Confidence Interval Half-Width	Min	Max	# Of Observations
No Degrade	1.90	0.24	0.09	1.46	2.30	30
10 % (Low) Degrade	3.13	2.79	1.04	1.63	13.50	30
20% Degrade (w/o Outliers	243.00 (3.33)	731.00 (2.53)	273.00 (1.0)	1.66 (1.66)	2400.00 (12.40)	30 (27)
30% (Med) Degrade	722.00	1090.00	407.00	2.19	2400.00	30
40% Degrade	2200.00	192.00	72.90	2010.00	2400.00	30
50% (High) Degrade	2200.00	192.00	72.90	2010.00	2400.00	30

The 10 and 20 percent degradation scenarios were almost identical, with the exception of 3 data points for the 20% scenario. The 10% increase in GPS signal degrade was not enough to adversely affect the ability to receive the GPS signal. These data points were determined to be statistical outliers. If those three data points are deleted and a means comparison test for different sample sizes is used there is no statistically significant difference between the means of the 10% scenario and the 20% scenario at the $\alpha = 0.05$ level. This is displayed in Table 9. Testing was accomplished by creating a confidence interval on the difference in the observed results of the two scenarios as required when comparing two different simulation situations (Hartman, 2-28). A

comparison of two scenarios that result in a confidence interval that contains zero is considered to be not statistical different.

Table 9. Means Comparison Test

Scenario	Difference in Means (X_2-X_1)	T(n_1+n_2-2, α)	Lower Bound	Upper Bound
10% vs 20%	239.87	2.011739	239.35	240.39
10% vs 20% (minus outliers)	0.20	2.0141033	-0.334	0.734

In addition, the last two scenarios, 40% and 50%, show no difference in degradation. This is due to simulated thresholds for GPS and INS accuracy within GIANT. When a GPS signal is unavailable, GIANT uses modeled INS drift error to calculate position location. This INS drift error is used until a GPS signal is acquired. If GPS is never reacquired then the position error continues to grow based on the INS drift error. Therefore in the 40% and 50% scenario, GPS signal is unavailable to the GPS receiver onboard the F-15E and INS drift error is used to obtain position information.

As a result of the analysis of the initial handoff error, the original design factors of degrading GPS in 10% decrements was reduced from six to four factors: no, low (10%), medium (30%), and high (50%) degradation. This is represented in Table 10 as before each factor will be tested to determine if there is any difference in the means at the α = 0.05 level. The resulting horizontal handoff error is displayed in Figure 18. This handoff error is used as the initial weapon system error upon release from the launch platform

Table 10. Reduced Design of Experiment

2-Factors	6-Levels
Initial Degrade	No Initial degrade
	Low (10%) Initial Degrade
	Med (30%) Initial Degrade
	High (50%) Initial Degrade
Degrade After Weapons Release	No Degrade After Release
	Low (10%) Degrade After Release
	Med (30%) Degrade After Release
	High (50%) Degrade After Release

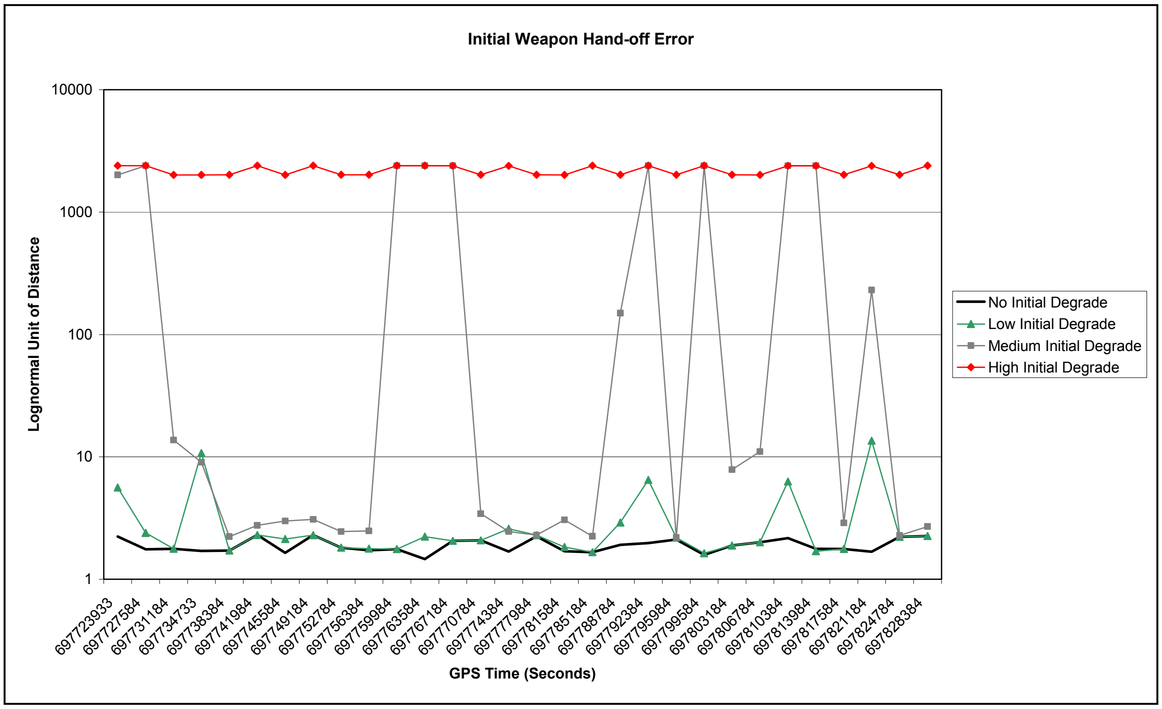


Figure 18. Limited Horizontal Hand-off Error

Figure 18 contains a series of 4 lines graphed. These lines are based on the horizontal handoff error points for each modeled scenario and are connected to depict the variation in error…. The bottom-most line, No Initial Degrade, represents the horizontal accuracy error of the F-15E when no degradation in GPS signal is present. This position error is transferred to the munition upon weapon release. For the No and Low Initial Degrade scenarios, horizontal error is minimally affected and in fact are not statistically different at the $\alpha = 0.05$ level. However, in the Medium Initial Degrade scenario, fluctuations in position accuracy can be seen. This is due to the Dilution of Precision (DOP) mentioned earlier. These normal fluctuations are exaggerated when the satellite signal strength is degraded. This implies that Medium Initial Degrade provides additional error to the expected normal position errors.

Figure 19 displays the initial error in terms of CEP at the 50% level and Figure 20 displays the CEP at the 95% level. This indicates that 50% and 95% of the outcomes, respectively, will fall within the indicated radius. As would be expected, the CEP at the 50% level is more closely grouped than at the 95% level. If no degrade was experienced during the F-15E's flight, its true location would be expected to fall inside the central region of both graphs 50% and 95% of the time respectively. Minor fluctuations are seen with low degradation and larger fluctuations are seen with medium degradation. At high GPS degradation the CEP radius expands out to an approximately 2400 unit of distance radius. However, even at the 95% level, the CEP is still within 10 meters for the No Degradation and Low Degradation scenarios.

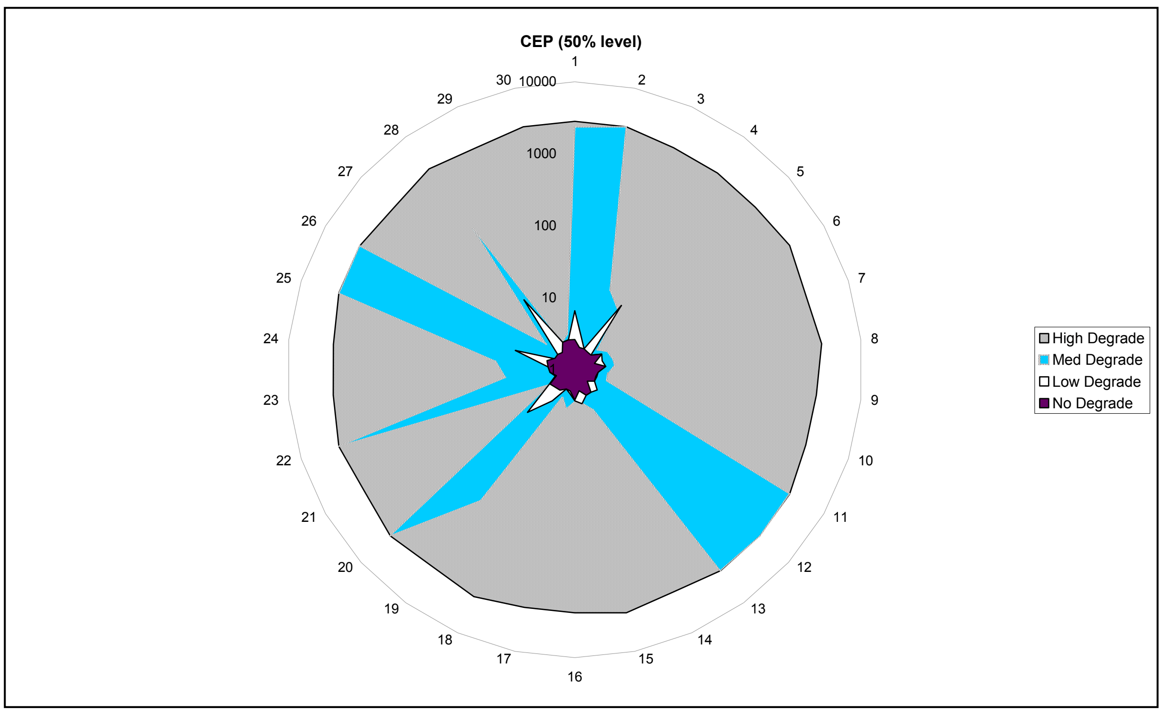


Figure 19. 50% CEP at Hand-off

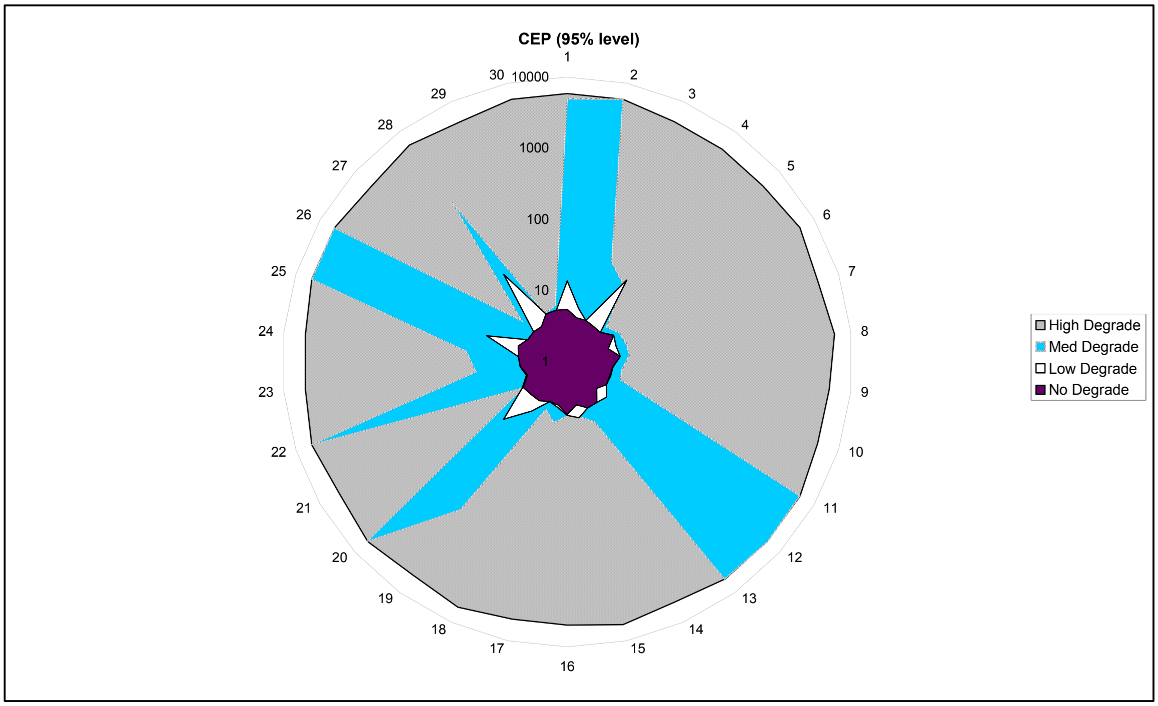


Figure 20. 95% CEP at Hand-off

Figure 19 and 20 indicate that when low or medium degradation of GPS is likely, time of day is a major factor in hand-off accuracy as seen in the fluctuations on the graph in this pilot study. Due to DOP and reduced GPS signal strength, some variance in weapon accuracy is expected. Under high degradation, time of day or satellite position has less impact on weapon accuracy, as the GPS signal is effectively unavailable. Of course, directional consideration and jammer placement will need to be considered in an actual test case of jammer effects.

Weapon modeling runs were accomplished using the handoff errors described above for initial error upon free-fall of the weapon. The released JDAM was modeled in GIANT against a stationary target. The four levels of satellite signal degradation were

then used to measure the error in weapon accuracy. This was accomplished by subtracting the initial handoff error. Table 11 provides initial analysis on the horizontal 1-sigma and 95% CEP weapon error. As GPS is degraded, accuracy decreases as initially expected. However, degradation after weapon release has a greater impact on weapon accuracy in this pilot study. Figure 21 displays this horizontal 1-sigma weapon error increase graphically. This is the difference in the true target location or desired mean point of impact (DMPI) and the actual point of impact.

Table 11. Weapon Position Error Scenario Results

Initial GPS Degrade	GPS Degrade After Weapons Release							
	No Degrade		Low Degrade		Medium Degrade		High Degrade	
	Horizontal Error	$CEP_{(95\%)}$	Horizontal Error	$CEP_{(95\%)}$	Horizontal Error	$CEP_{(95\%)}$	Horizontal Error	$CEP_{(95\%)}$
No Degrade	6.43	15.74	5.71	13.98	646.00	1581.24	2317.39	5672.38
Low Degrade	7.29	17.84	6.06	14.83	646.00	1581.24	2318.62	5675.4
Medium Degrade	690.00	1688.95	667.00	1632.65	667.00	1632.65	2320.52	5680.05
High Degrade	2160.00	5287.13	2160.00	5287.13	2160.00	5287.13	2226.27	5449.35

Figure 21. Horizontal 1-Sigma Weapon Error

As displayed in Figure 21, it appears that No and Low Degrade scenarios do not adversely affect weapon accuracy. However, upon medium degradation of the GPS signal after weapon release, the No and Low Degrade scenario's accuracy decreases significantly. It should be noted that improved GPS signal after weapon release cannot compensate for the initial error as indicated by the Medium and High Degrade scenarios. While the JDAM does have control surfaces, these are small and unable to compensate for a great deal of error. The length and time of weapon descent also plays a factor.

To test the hypotheses on Figure 21, the differences in scenarios were compared and confidence intervals created at the $\alpha = 0.05$ level (Hartman, 2-28). Table 12 provides data for each scenario to include: mean, standard deviation, and half-width, at the 95% level of confidence.

Table 12. Scenario Confidence Intervals

X1	X2	Mean	Std Dev	Half-Width	Min	Max	# of Obs
No	No	6.43	0.41	0.15	4.45	6.83	30
Low	No	7.29	2.37	0.89	4.45	15.20	30
Med	No	690.00	1080.00	413.00	6.68	2410.00	30
High	No	2160.00	441.00	162.00	6.68	2410.00	30
No	Low	5.71	1.57	0.59	1.06	6.68	30
Low	Low	6.06	1.61	0.60	1.06	10.70	30
Med	Low	667.00	1070.00	401.00	6.68	2410.00	30
High	Low	2160.00	446.00	167.00	6.68	2410.00	30
No	Med	646.00	1060.00	389.00	6.68	2410.00	30
Low	Med	646.00	1060.00	389.00	6.68	2410.00	30
Med	Med	667.00	1070.00	401.00	6.74	2410.00	30
High	Med	2160.00	446.00	167.00	6.74	2410.00	30
No	High	2320.00	450.00	171.00	6.68	2410.00	30
Low	High	2320.00	450.00	171.00	6.68	2410.00	30
Med	High	2320.00	443.00	165.00	6.74	2410.00	30
High	High	2230.00	187.00	69.70	2030.00	2410.00	30

Table 13 provides a summary of the means comparison tests on the significance of the difference of each modeled scenario. Reading this table, one can see that there is no statistical significance between No and Low Degrade scenarios at the $\alpha = 0.05$ level. However, there is a statistically significant difference between the No/Low Degrade scenario and each of the Medium and High Degrade scenarios at the $\alpha = 0.05$ level.

Table 13. Scenario Statistical Significance

<table>
<tr><th colspan="5">Significance of Degrade Scenarios (α = 0.05)</th></tr>
<tr><th></th><th>No</th><th>Low</th><th>Med</th><th>High</th></tr>
<tr><td>No</td><td colspan="2" rowspan="2">No Significant Difference</td><td rowspan="2"></td><td rowspan="3"></td></tr>
<tr><td>Low</td></tr>
<tr><td>Med</td><td colspan="3">No Significant Difference</td></tr>
<tr><td>High</td><td colspan="4">No Significant Difference</td></tr>
</table>

The other measure of interest is the probability of kill or P_k. Table 14 displays the expected P_k for each scenario while Figure 22 displays this graphically for each run. Again the chart depicts Initial Degrade against Degrade After Weapon Release. Within GIANT, a P(k) below 80 % requires additional weapons on target to reach a level of confidence on target destruction.

Table 14. Modeled Weapon System P_k

Initial GPS Degrade	No Degrade	Low Degrade	Medium Degrade	High Degrade
No Degrade	0.80	0.80	0.51	0.04
Low Degrade	0.78	0.78	0.51	0.04
Medium Degrade	0.51	0.51	0.51	0.04
High Degrade	0.04	0.04	0.04	0.01

As indicated in Table 14 and displayed in Figure 22, GPS availability has a major impact on weapon lethality. As the degradation after weapons release increases, P_k decreases. No Initial Degrade P_k is around 80% with little or no fluctuation until

degraded to the medium level. Upon high degradation, all scenarios' P_k drops to approximately zero.

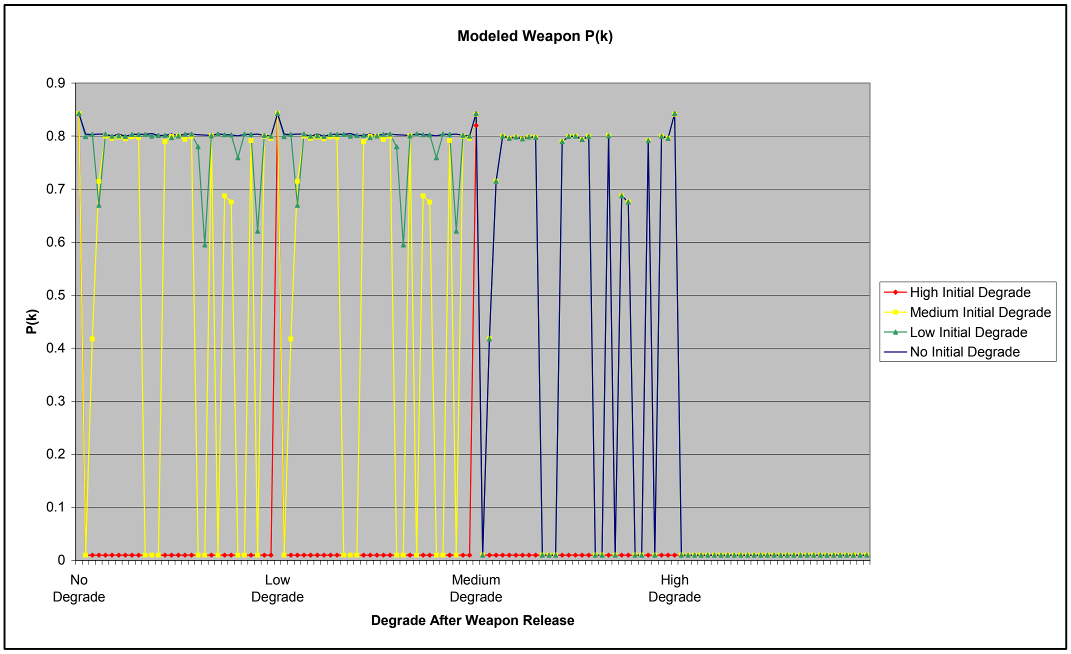


Figure 22. Weapon P_k

While it has been shown that GPS availability, or the lack thereof, can affect weapon performance (e.g., accuracy and lethality), a more detailed analysis must be performed to understand how initial degradation and GPS availability after weapon release affect weapon accuracy. With the available data, response surface methodology (RSM) can be employed to help understand the interactions of Initial Degrade and Degrade after Weapon Release on horizontal 1-sigma weapon error. Initial experiments with fitting the results to a predictable model indicated no interaction between the No Degrade scenario and the Low Degrade scenario as was witnessed in the figures and tables above. Therefore, the No Degrade scenario was removed. The resulting scenarios

offer a two-factor, three-level design of experiments (DOE). Table 15 displays the design factors and levels for the DOE. "RSM is useful for analyzing problems in which several independent variables influence a dependent variable" (Montgomery, 445). Of course, the goal of RSM is to optimize the response. For this research effort, RSM is used to explain the modeled results and their interaction and demonstrate another possible analysis.

Table 15. Design of Experiments

Factors	Levels	
Initial Degrade	-1	Low Degrade
	0	Medium Degrade
	1	High Degrade
Degrade After Weapons Release	-1	Low Degrade
	0	Medium Degrade
	1	High Degrade

Due to nonlinear interactions discovered in the initial experiment, a second-order model was fitted using SAS JMPin 4.0.2 (Academic) statistical software. Figure 23 summarizes the results of the JMPin analysis. By analyzing these outputs, an understanding can be gained regarding the interactions of our two factors and weapon accuracy. The first significant result is gleaned from the R-square value. This value represents the overall appropriateness of the model at explaining the variability in the data. At 0.73, this fitted model explains a large percentage of the variability at least in the pilot study. While there appears to be an extremely high mean square error (MSE) this is due, in part, to the scale of the data. Because our unit of distance range as shown in Table 12 goes from 6.68 to 2410.00, our MSE was rather large. To confirm this

scaling issue, multiplying the data by 0.001 dropped the MSE from 2822755 to 2.82275 with no change to R-square or F-values.

Summary of Fit

RSquare	0.729651
RSquare Adj	0.724531
Root Mean Square Error	0.601054
Mean of Response	1.246432
Observations (or Sum Wgts)	270

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	3	8.468264	2.82275	8.4774
Pure Error	261	86.905830	0.33297	Prob > F
Total Error	264	95.374094		<.0001
				Max RSq
				0.7537

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Initial Degrade	1	1	63.079210	174.6062	<.0001
Degrade After Weapon Release	1	1	81.365951	225.2248	<.0001
Initial Degrade*Degrade After Weapon Release	1	1	37.690525	104.3292	<.0001
Initial Degrade*Initial Degrade	1	1	62.964028	174.2874	<.0001
Degrade After Weapon Release*Degrade After Weapon Release	1	1	12.308015	34.0692	<.0001

Figure 23. RSM Results Obtained from JMPin

Reviewing the p-values provided in Figure 23, we see that the two main effects (Initial Degrade and Degrade After Weapons Release) significantly change (p-value < 0.05) the horizontal 1-sigma weapon error. In addition, the interaction effects also significantly change the horizontal 1-sigma weapon error.

The validity of the model at predicting the interaction of Initial Degrade and Degrade After Weapons Release would not be comprehensive if the residuals were not normally distributed. The residuals are the difference between the observed value and the predicted value (Neter, 25). It is important to plot the residuals and check for normality to validate the fitted model because normality was an assumption required by this technique. The results of this normality confirmation are listed in Figure 24. While the

residuals are not exactly normally distributed, the moderate departures from normality do not imply a lack of model validity (Montgomery, 86). In Figure 24, there is slight departure from normality. However, for this size of samples it is not significant.

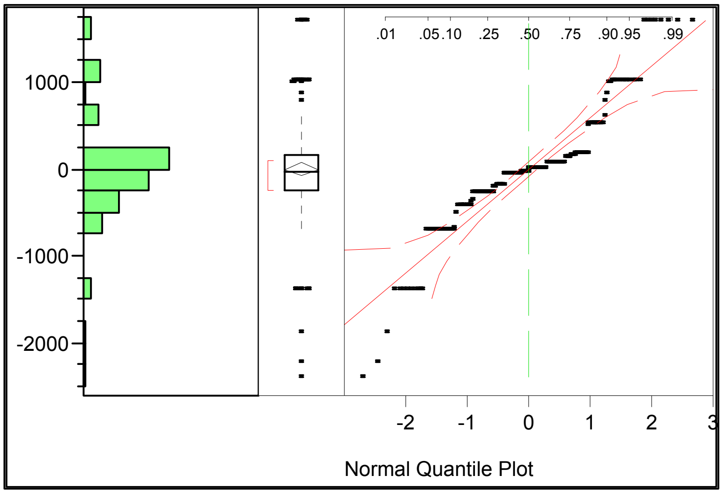


Figure 24. Residual Distribution Plot

After the model validation process, the model can be used for predictions. The fitted model is a quadratic relation. "It is unlikely that a polynomial model will be a reasonable approximation of the true functional relationship over the entire space of the independent variables, but in a relatively small region they usually work quite well" (Montgomery, 446). As proven earlier, the model is a good fit over our limited data set. This may not be true for an expanded example; however, similar analysis might yield an improved model. The model parameter estimates are displayed in Table 16 and the resulting model is given below and is graphically displayed in Figure 25.

Table 16. Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.261553	0.081793	3.20	0.0016
Initial Degrade	0.5919798	0.0448	13.21	<.0001
Degrade After Weapon Release	0.672334	0.0448	15.01	<.0001
Initial Degrade*Degrade After Weapon Release	-0.560435	0.054868	-10.21	<.0001
Initial Degrade*Initial Degrade	1.0244025	0.077596	13.20	<.0001
Degrade After Weapon Release*Degrade After Weapon Release	0.4529167	0.077596	5.84	<.0001

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 - \beta_3 X_1 X_2 + \beta_4 X_1^2 + \beta_5 X_2^2$$

$$Y = 261.55 + 591.98 X_1 + 672.33 X_2 - 560.44 X_1 X_2 + 1024.40 X_1^2 + 452.92 X_2^2$$

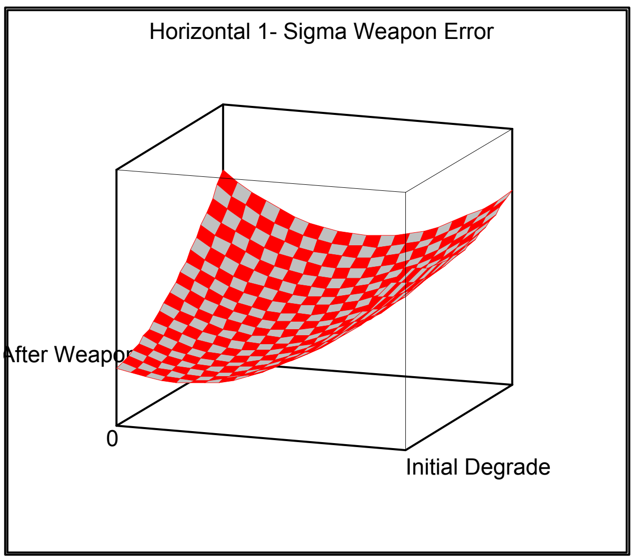


Figure 25. Response Surface for Horizontal 1-Sigma Weapons Error

For this modeled scenario, this equation can be used to determine the predicted horizontal weapon error given a particular degrade scenario. For example, if during mission planning it is discovered that medium GPS degradation can be expected in theater and low GPS degradation is anticipated at or near the target, the level effects provided in Table 15 can be used to predict weapon accuracy.

X1 = Medium = 0, X2 = Low = -1, Y = 42.2 units of distance error

Of course, this equation is based on the small, illustrative example and does not include other elements such as error caused by wind or direction and placement of GPS signal jammers. The approach, however, could be applied to a much larger example. Ideally, if this were done for every key drift effecter, a predictive measurement could be developed that could then apply space-based effects of GPS to JMEM.

Overall Findings

It is clear from this research effort that the lack of GPS can adversely affect the accuracy of a JDAM weapon. Minor GPS signal degradation should not significantly decrease accuracy if it occurs prior to weapon release or during weapon freefall due to small initial error and freefall geometry. Minor GPS signal degradation would be created by small handheld or vehicle-mounted jammers with a small signal strength output (1-10 watts). With larger jammers, weapon accuracy will be affected adversely whether it occurs during weapon freefall or before weapon release. If GPS degradation affects weapon handoff, unguided weapons will be off course before or upon release. As these gravity bombs have little to no guidance or error correction capability, the error will only grow as it falls based on its speed and trajectory.

If an adversary or ally chooses to jam the GPS signal, the signal is jammed for all receivers within range of the jammer, affecting both adversary and allied receivers. This is an important concept to understand when determining whether GPS degradation may occur in the area of operations. A less technologically advanced country like Afghanistan does not use GPS for military operations and might be expected to use GPS jamming to deny its use to its adversaries. In contrast, the intentional degradation of GPS by a more

technologically advanced country may be less likely as they may use GPS for military and civil operations. There are other less superior methods used for navigation and positioning. Both Russia and China have positioning systems, however, at the open-source level of information it is unclear whether Russia's system is inferior or technically equal to our GPS system. It may be possible to jam our signal while maintaining the use of their system. To more completely model GPS in this environment, directional jammers should be incorporated along with different types of guided and unguided munitions against both stationary and moving targets. Also the number of replications should be increased to not only simulate longer operations windows but to develop tighter levels of confidence in output analysis.

As measured, for this small facet of the GPS, military effectiveness can be modeled by the number of sorties required to ensure target destruction. Increasing degrade on the GPS signal would have the effect of increasing the number of aircraft sorties flown against a particular target as the probability of kill decreased as jamming increased. However, this measure may not directly translate into a total military effectiveness for GPS. After this process has been accomplished for every critical use of GPS, a method of aggregation will be required to determine the total effectiveness of GPS.

V. CONCLUSIONS

Introduction

This chapter reviews the importance of this research as well as the major issues covered during this research. The major findings of the literature are also summarized. This is followed by a review of the results of efforts to assess the issues in modeling the effectiveness of space. The chapter concludes with recommendations for future research relating to this topic.

Literature Review Findings

Joint space doctrine does not officially exist. As a result, clear official direction to operators is unavailable. As military doctrine is the foundation of determining military effectiveness or worth, it is difficult to assess space's worth and therefore to evaluate modeling space. In the absence of joint doctrine, AFSPC has developed space doctrine to provide Air Force operational direction and establish responsibilities. With the recent selection of General Lance Lord as AFSPC/CC, the Space Commission's opinion that AFSPC become the DOD executive agent for space appear to have been approved. With other recent developments, such as the President's decision to withdraw the U.S. from the 1972 ABM Treaty, space may be transitioning from a support function to an operational function similar to airpower's transformation after World War I.

Specific models with required levels of fidelity for comprehensive space modeling is not complete. Available models contain large gaps in representation. Figure 6 in Chapter II provided a visual representation of the issue of level of fidelity in space

modeling. Current mission and system level models, those at a high level of fidelity, do a good job at representing the aspects of space. The theater and campaign level models, those at a low level of fidelity, do a poor job of representing the aspects of space. What is required is a method of aggregating the representation of space aspects in high fidelity models into intermediate and lower level fidelity models.

Relevance of the Research

The DOD is relying on space for operational mission support at an ever-increasing rate. If this reliance on space is not understood, the U.S. and its national security become more vulnerable to operational degradation and mission failure as the result of space information degradation or denial. This thesis attempts to identify a framework in organizing the interactions and responsibilities among space systems, system owner/operators, and space-based information users. These are all necessary steps in accurately modeling space.

Recommendations for Future Research

Space is clearly not well represented in the various theater level models as outlined in Chapter II. However, as Chapter IV illustrates, space is better represented in some system-level or high fidelity models and simulations. What is missing is a way of aggregating that high fidelity information into the theater level models. In addition, is the theater or campaign level models valid for measuring the military worth of space or does a Global level model need to be created? Missing is appropriate measures for determining spaces' global military worth. What is the ultimate measure of a battle or a campaign? Is winning a Pyric victory winning? Is a military "win" that results in a

political loss a victory? What is the measure of a conflict deterred because of information superiority?

As was seen in the illustrative example, the classical measures used to relate space worth to the warfighter, may not directly measure the military worth of space. A clear understanding of the space missions and those impacted by space is required before any further research can be accomplished in measuring the military worth of space. Future studies should use the proposed process in this thesis to gain insight into the other critical missions supported by space-based systems. This is required, regardless of the level of fidelity. A method of aggregating this system level model detail into theater or campaign level models is a complex but necessary task.

APPENDIX A. SIMULATION STUDY DETAILS (LAW, 84-86)

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1. *Formulate the problem and plan the study*.

a. Problem of interest is stated by manager.

b. One or more kickoff meetings for the study are conducted, with the project manager, the simulation analysts, and the subject-matter experts (SMEs) in attendance. The following issues are discussed:

- Overall objectives of the study
- Specific questions to be answered by the study
- Performance measures that will be used to evaluate the efficacy of different system configurations
- Scope of the model
- System configurations to be modeled
- Software to be used
- Time frame for the study and the required resources

2. *Collect data and define model*.

a. Collect information on the system layout and operation procedures.

- No single person or document is sufficient
- Some people may have inaccurate information—make sure that true SMEs are identified
- Operating procedures may not be formalized

b. Collect data (if possible) to specify model parameters and input probability distributions.

c. Delineate the above information and date in an "assumptions document," which is the *conceptual model*.

d. Collect data (if possible) on the performance of the existing system (for validation purposes in step 6).

e. The level of model detail should depend on the following:

- Project objectives
- Performance measures
- Data availability
- Credibility concerns
- Computer constraints
- Opinions of SMEs
- Time and money constraints

f. There need not be a one-to-one correspondence between each element of the model and the corresponding element of the system.

g. Interact with the manager (and other key project personnel) on a regular basis.

3. *Is the conceptual model valid?*

a. Perform a structured walk-through of the conceptual model using the assumptions document before an audience of managers, analysts, and SMEs.

- Helps ensure that the model's assumptions are correct and complete
- Promotes ownership of the model
- Takes place *before* programming begins to avoid significant reprogramming later.

4. *Construct a computer program and verify.*

a. Program the model in a programming language or in simulation software. Benefits of using a programming language are that once one is often known, they have a low purchase cost, and they may result in a smaller model executions time. The use of simulation software, on the other hand, reduces programming time and results in a lower project cost.

b. Verify (debug) the simulation computer program.

5. *Make pilot runs.*

a. Make pilot runs for validation purposes in Step 6.

6. *Is the programmed model valid?*

a. If there is an existing system, then compare model and system performance measures for the existing system.

b. Regardless of whether there is an existing system, the simulation analysts and SMEs should review the model for correctness.

c. Use sensitivity analysis to determine what model factors have significant impact on performance measures and, thus, have to be modeled carefully.

7. *Design experiments.*

a. Specify the following for each system configuration of interest:

- Length of each run
- Length of the warmup period, if one is appropriate
- Number of independent simulation runs using different random numbers—facilitates construction of confidence intervals

8. *Make production runs.*

a. Production runs are made for use in Step 9.

9. *Analyze output data.*

a. Two major objectives in analyzing output data are:

- Determining the absolute performance of certain system configurations
- Comparing alternative system configurations in a relative sense

10. *Document, present, and use results.*

a. Document assumptions, computer program, and study's result for use in the current and future projects.

b. Present study's results.

- Use animation to communicate model to managers and other people who are not familiar with all of the model details.

- Discuss model building and validation process to promote credibility.

c. Results are used in decision-making process if they are both valid and credible.

APPENDIX B. SPACE, MISSILE DEFENSE, & IO M&S CATALOG

The following information was provided by MAJ Bill McLagan of USSPACECOM/AN and is dated 1 August 2001.

Advanced Real-Time Gaming Universal Simulation (ARGUS): ARGUS models the offensive and defensive ballistic missile environment from strategic to tactical ballistic missile attack. It is used to analyze C2 structures for the future national missile defense system. Will be replaced by WARGAME 2000.
POC JNTF, Maj Joe Moles, 719-567-9931

Advanced Regional Exploratory System (ARES): ARES is being developed as the Army's new theater campaign analysis model. ARES is an event-driven, deterministic, variable resolution, object-oriented simulation that will support analysis of joint/combined land, air and maritime force operations, including force sufficiency and OPLAN testing in a wide range of potential threat and operational conditions, such as multi-sided, and/or, nonlinear-combat environments. ARES supports information operations analyses by emphasizing information flow from sensors over communications paths to command and control nodes. ARES supports the use of ground truth or perception modes of operation. While ground truth mode uses perfect knowledge of the battlespace, perception mode limits each decision-maker to only that information his/her unit's organic sensors have collected and any information reported by subordinate and superior units and then fuses that information into a battlespace view unique to that particular command node. ARES uses "effectors" to support sensitivity analyses on the effects of destruction, disruption, or exploitation of command, control, communications and intelligence nodes and associated assets. ARES will offer three mechanisms for modeling command & control: a) the use of rulebases for automated command & control, currently representing a reactive control process; b) scripted OPLAN/OPORD scenarios or c) a combination of rulebase and scripted C2.
POC USALIWA, Mr. Berlin Lewis, bklewi2@vulcan.belvoir.army.mil, 703-681-6359 or USACAA, Mr. Wally Chandler, chandler@caa.army.mil, 301-295-1692

Adversary: Adversary is a communications network-modeling tool used to analyze communication infrastructures and then convey the results of analyses in graphic format. It uses an editable baseline and point-and-click analytic processes displayed on an OILSTOCK map. Adversary provides a usable set of tools for both effective support to military planning/targeting assessment and SIGINT target development and cataloging.
POC NSA, Adversary PMO, 301-688-6570

Arena: This application acts as an arena within which information operations models, simulations and data are integrated. Arena presents an integrated view of various command and control aspects including electronic warfare, communications structure and performance, targeting, command and control structure and national infrastructure.
POC JIOC, Mr. Larry Whatley, larry.whatley@jioc.osis.gov, 202-977-4758

Battle Area Regions Threatened (BART): BART is a PC-based, graphical strategic ballistic missile defense analysis model designed to estimate the number of ground-based interceptor shoot-look-shoot opportunities and other engagement characteristics.
POC NORAD, Dr. Murray Dixson, murray.dixson@peterson.af.mil, 719-554-3781

Builder: The Interactive Scenario Builder models the electromagnetic environment and allows the user to create deterministic scenarios as a mission-planning tool. Radar beams and coverage using various propagation models are displayed on a DTED map and the effects of terrain masking visualized. The effects of radar jamming also can be displayed. With the Aurora feature, communications links and networks can be visualized. An RF coverage visualization tool shows the energy being radiated by a transmitter. Communications receiver coverage allows the user to analyze what would happen if you tried to jam a communications link.
POC NRL, (Radars) Dr. Larry Schuette, schuette@nrl.navy.mil, (202) 767-6814
POC NIWA, (Communications) Rosemary Wenchel, wenchell@niwa.navy.mil, (202) 767-1493

C2W Analysis and Targeting Tool (CATT): CATT provides a simulation capability of an adversary's Integrated Air Defense System (IADS) and the capability for analysts to do sensitivity analysis on alternative actions. It includes end-to-end modeling of IADS processes such as detection, tracking, weapons allocation, communication, decision-making and engagement. The model's primary C2W actions include inserting and removing various user defined flight paths and removing various communications links and radar posts.
POC AFIWC/SAA, LtCol Ross Ziegenhorn, raziege@afiwc.osis.gov, 210-977-2427

C4ISR Model: The C4ISR Model is a federation of five interacting simulations used to integrate C4ISR and combat operations in analysis of joint force campaigns. The five models are combat, command and control, sensor, communications assessment and information.
POC DISA/D83, Carroll Mitchell, 703-696-9181

C4ISR, Space and Missile Operations Simulation (COSMOS): COSMOS has been developed to support analysis of the performance of C4ISR, space and missile systems. COSMOS explicitly models collection systems for SIGINT, IMINT and HUMINT as well as surveillance systems using visible, IR, LADAR and RADAR technologies. The resources and associated timelines required to process, exploit and disseminate the collected information are modeled using a flexible rule-based approach. COSMOS can also model systems in all Space Command mission areas including futuristic US and foreign space control systems such as Space-Based Lasers (SBL), Ground-Based Lasers (GBL) and Kinetic Energy ASATs (KEASAT). The model is currently in use supporting OSD, Joint Staff, Air Force, Army, Navy, Marine, Office of the Space Architect and classified customer analyses. COSMOS has been interfaced with community accepted classified models to support analysis of current and future system architecture performance. Versions of the toolset are available on SUN, Silicon Graphics

and TAC-3 workstations. COSMOS was developed and continues to be enhanced by the SAIC Pentagon On Site Team (POST).
POC Jeff Knox, SAIC 703 276-2116 JEFFREY.S.KNOX@saic.com

Communications Jamming Model (COMJAM): COMJAM is part of AFIWC's Improved Many on Many (IMOM) family of programs to model electronic combat scenarios. COMJAM's main purpose is to predict jamming effectiveness against the communications capabilities of both ground-based and airborne communications assets. The primary nodes of analysis are network, link and transmission rings analysis.
POC AFIWC/SAV, Capt Keith Harrington, kjharri@afiwc.osis.gov, 210-977-2706

Communications Modeling Tool (CNMTE): CNMTE is a tool designed to construct, model and analyze traffic for telecommunications networks. It provides a means to combine the network subscriber to the physical network and simulate traffic between subscribers. Simulation results present a picture of the network over time and answer such questions as how many calls were sent and received? What is the probability of calls being blocked? What is message delay? And what percent of bandwidth is used? CNMTE is applicable to network analysis for offense or defense.
POC JIOC, Mr. Lawrence Whatley, larry.whatley@jioc.osis.gov, 210-977-4758

EDGE Developer Option: EDGE Developer Option is a commercial off-the-shelf set of visualization, simulation and analysis tools and applications that allow you to create a rich synthetic environment and view the world from outer space to sea level. The foundation is the EDO Visualization Component. Additional components provide libraries for integrating imagery, maps, terrain, time and weather. The Ascent tool for launch vehicle trajectory simulation component can also run as a stand-alone program.*http://www.autometric.com*

Extended Air Defense System (EADSIM): EADSIM is a system-level simulation used by combat developers, materiel developers and operational commanders to assess the effectiveness of theater missile defense (TMD) and air defense systems against the full spectrum of extended air defense threats. EADSIM models fixed- and rotary-wing aircraft, tactical ballistic missiles, cruise missiles, infrared and radar sensors, satellites, command and control structures, sensor and communications jammers, communications networks and devices, and fire support in a dynamic environment which includes the effects of terrain and attrition on the outcome of the battle. The tool provides analysts and training audiences insights into TMD architecture, battle management, system employment for maximum effectiveness, force structure analysis and mission planning.
POC Army Space and Missile Defense Command, Mr. Jim Watkins, jim.watkins@smdc.army.mil, 256-955-1681

Extended Air Defense Testbed (EADTB): EADTB allows the analyst to model a broad range of military missile defense applications from the fire unit level to the theater level in a constructive simulation framework. Its object-based simulation architecture supports this range by allowing the user to develop system models called specific system representations, or SSRs. The user/analyst can place numbers of these tailored simulated

systems on a host game board without having to rewrite other existing systems models or modify the supporting architecture. A major strength of EADTB is the capability to model the BMC4I to the level necessary to answer complicated joint service interoperability issues. EADTB has obtained DIS compatibility and is pursuing HLA compliance at this time. BMDO has certified EADTB as Y2K compliant.
POC Army Space and Missile Defense Command, Mr. Moody Parsons, parsonsg@smdc.army.mil

Global Positioning System End-to-End Model (GLEEM): GLEEM was developed to assist in analysis of capabilities and vulnerabilities of Global Positioning Systems/Inertial Navigation Systems (GPS/INS) in aircraft and guided munitions. GLEEM allows projection of GPS receiver performance in signal lock maintenance while in a hostile or benign environment and simulates various combinations of antennas and receivers, on multiple platforms, with multiple jammers. Friendly interference platforms can be included as well.
POC AFIWC/SAV, Lt Michael Perry, mjperry@afiwc.osis.gov, 210-977-2706

GPS Interference and Navigation Tool (GIANT): GPS Interference And Navigation Tool (GIANT): GIANT is a constructive and repeatable engagement/mission level simulation that calculates the impact of navigation performance on warfighter measures of effectiveness (e.g., Target Kills). A GIANT scenario consists of a GPS/INS-equipped platform moving over digital terrain (i.e., DTED) on a WGS-84 earth under a moving GPS constellation transmitting multiple codes on multiple frequencies. GIANT can represent any air or ground vehicle with or without weapons. Weapons also have GPS/INS navigation systems and the launch platform to weapon handoff event is modeled. As an option, any number of stationary or moving GPS jammers can be present. Target miss distance and probability of kill is thus traceable to the weapon and the launcher. Many measures of performance and time histories are calculated and output. GIANT has been used to support numerous Navwar and EW studies, is validated, accredited, and included in the AFSAT.
POC SMC/CZE, Capt Trent Causey, joseph.causey@losangeles.af.mil, 310-363-2937

Guardian: Guardian provides visualization and analysis of space system and architecture susceptibility to counterspace threats. Guardian supports modeling of radio-frequency (RF) jamming, air-, ground-, and space-based laser phenomenologies, high power microwave threats, and direct-ascent anti-satellite (ASAT) systems. Guardian has the capability to model the interruption of system commanding, target imaging, and data download to ground stations. Guardian has been used to explore the effects of jamming uplink communications of commercial satellite architectures.
POC: USAF/SMC/XR

Information Operations Navigator (ION): ION provides its users a standardized, structured methodology for generating the IO portions of an OPLAN in Joint Operational Planning and Execution System (JOPES) format and for identifying IO targets for a Candidate Master Target List. ION is based on strategies-to-task methodology to derive IO objectives from overall CINC objectives. The user identifies the effects IO must

induce on an adversary in order to accomplish the IO objectives, and this information is used to write the corresponding IO tasks.
POC JIOC, Ms. Regina Walker, regina.walker@jioc.osis.gov, 210-977-2911

Integrated Modeling and Analysis Suite (IMAS): IMAS models missile launches to determine origin and threat. It is used to develop inputs for Integrated Theater Warning and Attack Assessment (ITW/AA) end-to-end system integrity tests.
POC NORAD/USSPACECOM/J6C, Mr. Ron Stephens, ronald.stephens@peterson.af.mil, 719-554-9704

Joint Simulation System (JSIMS): JSIMS is the next generation simulation for joint training and exercises, replacing the Aggregate Level Simulation Protocol (ALSP) Joint Training Confederation (JTC). JSIMS provides the object-oriented environment and common services, such as databases, security protocols, a High-Level Architecture (HLA) compliant environment, and interfaces to real-world C4ISR systems, that the Services will populate with representations of their units and weapons systems. Each Service has reoriented its next-generation training simulation effort into populating JSIMS with the relevant objects. JSIMS Service components include the Warfighter Simulation 2000 (WARSIM 2000) for the Army, the National Air and Space [Warfare] Model (NASM) for the Air Force, JSIMS Maritime for the Navy and Marine Corps, the National Systems Simulation (NATSIM) for the National Reconnaissance Office, the WARSIM Intelligence Module (WIM) for tactical intelligence, and the Joint SIGINT Simulation (J-SIGSIM) for national signals intelligence. DISA is the Executive Agent for C4ISR systems simulation, and DIA is responsible for foreign systems performance and behavior. JSIMS IOC is set for Apr 2001, and FOC for Dec 2003. http://www.jsims.mil

Joint Warfare System (JWARS): JWARS is under development to be a state-of-the-art, constructive simulation that provides a multi-sided and balanced representation of joint theater warfare capable of use in analysis of planning and execution, force assessment, system effectiveness and trade-off analysis, and concept and doctrine development and assessment. It will be a balanced warfare representation including C4, ISR and logistics and will focus on the operational level of war. It will replace MIDAS and TACWAR. The Limited IOC version is due in Mar 2000, Full IOC in May 2001 and FOC in FY 2002. http://www.dtic.mil/jwars

Laser Threat Analysis System (LTAS): LTAS is a comprehensive computer modeling and simulation environment for assessing the operational impact of optical directed energy weapons and countermeasures. LTAS encompasses the solution spectrum from physical process models through comprehensive threat engagement models.
POC AFIWC/SAA, Jack Labo, jalabo@afiwc.osis.gov, 210-977-2427

Missile Defense Space Tool (MDST), formerly Portable Space Model (PSM): MDST provides the capability to support live and/or simulated exercises by injecting missile warning message sets into operational communications and simulation networks. MDST contains real time models designed to provide a representation of the Defense Support Program, the Satellite Based Infrared System (SBIRS), and elements of the Theater Event System at a sufficient level of fidelity to support exercises while operating in real time. It

provides theater commanders notification of theater ballistic missile launches via the Tactical Information Broadcast System (TIBS) and the Tactical Related Applications Data Dissemination System (TDDS).
http://www.jntf.ssd.mil/bmdssc/PSM/PSM_SW_Spec.htm

Model for Analysis of Sensor Coverage (MASC): A Windows-based application for computing the terrain-masked line-of-sight (LOS) coverage of ground, air and space-based sensors. Ground-based and airborne sensor coverage can be displayed in 2 and 3D while satellite LOS coverage is displayed as a 2D map.
POC NORAD, Dr. Murray Dixson, murray.dixson@peterson.af.mil, 719-554-3781

National Air & Space Model (NASM): NASM is the Air Force component of the Joint Simulation System (JSIMS). It is the successor to the Air Warfare Simulation (AWSIM). NASM is developing the mission space objects (systems, organizations and procedures) JSIMS will use to provide the functional capability to represent the full range of aerospace power applications in a joint synthetic battle space for both Air Force specific and joint training. Applications include training and readiness, education, doctrine development, situation assessment and the formulation, assessment and rehearsal of operational plans. The IOC version of NASM will likely include a limited depiction of all satellites (basic orbital characteristics) and higher fidelity models of missile warning (DSP & SBIRS), navigation (GPS), some satellite communications and foreign space control. By FOC the goal is to have fully integrated air and space in NASM & JSIMS. Version 1 (IOC) will be released March 2002 and the Air Force Full transition (AFFT) release will be September 2003 *http://www.wg.hanscom.af.mil/NASM/overview.html*

Naval Simulation System (NSS): NSS is an object-oriented, multiple-warfare and Monte Carlo simulation system. NSS is also High Level Architecture (HLA) compliant. It represents command and control, communications, computer, intelligence, surveillance, reconnaissance (C4ISR) processes and systems in a fully integrated and comprehensive fashion. This representation of C4ISR processes and systems specifically addresses: command structures and relationships; representation of operational plans; simulation of plan execution, including dynamic/responsive asset allocations; tactical picture generation; dissemination of surveillance products; and simulation of surveillance and intelligence product generation.
POC Navy, Space and Naval Warfare Systems Command (SPAWAR)

NORAD Air Defense Model (NADM): NADM is a PC-based, graphical strategic air defense simulation designed to estimate the outcomes of battles using specified threat scenarios and air defense architectures. Used in NORAD analyses and to support cruise missile defense analyses and exercises.
POC NORAD, Dr. Murray Dixson, murray.dixson@peterson.af.mil, 719-554-3781

NORAD/USSPACECOM Communications Simulation System (NUCSS): NUCSS replicates the communications string of the missile-warning component of Integrated Tactical Warning and Attack Assessment (ITW/AA). The model is maintained to reflect the current operational ITW/AA configuration. It provides a performance audit of the

current ITW/AA system under different threat scenarios and stress events such as link/node outages and degradation of the communications links, provides a method to evaluate technical development of the system and to improve its performance and provides a road map for incorporating future mission capabilities into the ITW/AA communications system. The simulation is able to federate under High Level Architecture with other models.
POC NORAD, Dr. Roy Mitchell, roy.mitchell@peterson.af.mil, 719-554-3718

Personal Computer Fighter Intercept Boundary (PCFIB) Model: PCFIB is a PC-based, graphical air sovereignty analysis model designed to determine intercept opportunities and locations for specified threats, surveillance systems, air bases, and interceptors. PCFIB is used to assess the air sovereignty effectiveness of force architecture.
POC NORAD, Dr. Murray Dixson, murray.dixson@peterson.af.mil, 719-554-3781

Radio Frequency Mission Planner (RFMP): RFMP provides the ability to evaluate jamming mission success for communications links. RFMP is a DII-COE GCCS-M software program that provides a visualization of RF propagation. RFMP integrates environmental variables and communication hardware statistics with RF propagation models to produce images that display geographical areas promoting RF reception/transmission/detection for use in mission planning. By providing an interactive and visual environment, RFMP allows the operator to develop familiarity with the RF environment before a mission occurs by playing a variety of what-if scenarios.
POC NIWA, Mr. Ernest Anastasi, anastasi@niwa.navy.mil, (202) 767-1493

Satellite & Missile Analysis Tool (SMAT): SMAT is a comprehensive 2-dimensional and 3-dimensional animated visual modeling tool for analysis of orbiting bodies, ballistic missile trajectories, and their relationship to the Earth. SMAT provides a fully modeled Earth with detailed geographic and political boundaries, has the capability to zoom and rotate the viewing position of the Earth, and provides accurate Sun position and illumination. Databases within SMAT contain the parameters for the Tactical Warning/Attack Assessment system, the Air Force Satellite Control Network, and the Space Surveillance Network sensors. SMAT allows complete control of all displayed sensor parameters, both ground and space-based, and allows importing, editing and saving of additional sensor parameters. SMAT provides the capability to model ballistic missile launch profiles, both strategic and theater, from any point on the surface of the Earth.
POC: Ms. Kathy Gue, USAF/SWC/DOG (Space Warfare Center) kathleen.gue@swc.schriever.af.mil

Satellite Navigation Accuracy Prediction Model (SNAPM): SNAPM was built to evaluate Global Positioning System (GPS) accuracy as a function of constellation geometry, equipment status and natural environmental events. The model is suitable for real-time evaluation of changing conditions experienced in a tactical warfighting environment. SNAPM represents all system components and elements that affect GPS user accuracy and availability. Applications include scenario evaluation/development, missile attack planning, aircraft operations planning and training. When used as a

mission simulation tool, SNAPM allows the viewing of collective information pertinent for evaluating and planning tactical decisions such as sortie timing, attack locations and other offensive/defensive measures. SNAPM output is presented on a workstation screen with colored hard copy available. SNAPM has been modified to run in a real-time constructive simulation environment, in both DIS and HLA environments, providing simulated GPS accuracies to other simulated systems. This instantiation of SNAPM also includes the ability to consider the impacts of GPS signal jamming/spoofing and weather effects.
POC USSPACECOM, Mr. Dave Peck, william.peck@peterson.af.mil

Satellite Tool Kit (STK): STK 4.0 (basic) is a free commercial off-the-shelf product that provides sophisticated modeling functions for space- and ground-based objects, such as satellites, ships, aircraft and land vehicles. Functions included in the free version of the software include vehicle propagation, determining visibility areas and times and computing sensor-pointing angles. Free STK provides animation capabilities and a two-dimensional map background for visualizing the paths of vehicles over time. Results can be generated in both textual and graphical formats. Additional modules can be purchased to provide enhanced computational and visualization capabilities. In particular, STK's Visualization Option (STK/VO) provides dynamic three-dimensional display of STK scenarios. A host of additional modules are available to provide detailed analyses for such tasks as determining satellite coverage over time, visibility related accesses for networks of objects, rapid analysis of close encounters between orbiting objects, realistic missile flight modeling, detailed modeling of radar systems and satellite communications link analysis. It addresses mission planning, launch and ballistic missile flight. STK is used to examine alternative deployments of satellites within constellations and analyze alternative coverage of combinations of satellites.
POC Analytical Graphics, Inc., Mr. Doug Claffey, 610-578-1080 or 1-800-220-4STK

Sensor Platform Allocation Tool (SPAAT): SPAAT is an ISR force structure analysis tool. It is a mixed integer program to select sensor architectures based on target coverage and cost constraints. SPAAT is used to determine the optimal mix of sensors and platforms required to accomplish the reconnaissance and surveillance mission. This optimization fits in the overall picture of the OODA (observe, orient, decide and act) loop at the orient/decide phase. ISR optimization bounds the feasible region of the trade space. An ISR mix that produces improved battle space knowledge can be fed into campaign or mission models to illustrate/quantify the military worth of ISR.
POC: Maj Mark Hunter, USAF/AFSAA

Space Command Optimization Utility Tool (SCOUT): SCOUT is a Mixed Integer Program utilizing Goal Programming to solve a Capital Budgeting problem. The model produces an investment roadmap: a mix of concepts, current systems, and launches that maximizes both task coverage and military value while adhering to constraints on budget, launcher demand, launcher availability, and logic governing the relationships of systems.

Spacecraft Simulation Toolkit (SST): The SST is an advanced, flexible development environment for the modeling of spacecraft and their environment. The SST is based upon state-of-the-art simulation methods and accurate physical phenomenology. It's an object-oriented system consisting of software objects, which simulate the various systems and subsystems of the physical spacecraft. The toolkit provides the ability to integrate the software objects together into a simulation of either a complete spacecraft system or a spacecraft subsystem. The SST uses visual programming to allow the user access to spacecraft system, payload or subsystem models through pull-down menus and their connection into control structures required to implement a simulation. The SST software objects provide algorithmic simulation of the various spacecraft functions. The simulation databases provide the necessary knowledge base within which the detailed characteristics of the system are described as well as an orderly and efficient means to store the results of a simulation for additional analysis. The interactive environment also provides integrated data analysis, software development tools and DIS interfaces with HLA interfaces currently under development. A key feature of the SST is its flexibility to be reconfigured to meet a wide variety of requirements in engineering, simulation, operations and training. Simulations that have been or are being developed include: Ultra Lightweight Imaging Technology Experiment (UltraLITE), Space-Based Radar (SBR) AMTI/GMTI, Global Positioning System (GPS), Hyperspectral Imaging (HSI), Advanced Geosynchronous Studies (AGS) and the Next Generation Space Telescope (NGST).
POC Air Force Research Laboratory, Dr. Rich de Jonckheere, rich.dejonckheere@vs.afrl.af.mil, 505-846-5054

Spectral and In-band Radiometric Imaging of Targets and Scenes (SPIRITS): SPIRITS is used to support electronic combat (EC) analysis, EC weapon effectiveness, aircraft-weapon-sensor acquisition, research, test and evaluation, tactics development, mission planning and training. SPIRITS is a simulation model used to scientifically predict the infrared signature of an aircraft under many operational conditions. SPIRITS simulates the emission of IR radiation due to the exhaust plume, hot parts, aerodynamic heating, reflected radiation due to sunshine, earthshine, cloud shine and the atmosphere. Outputs provided are in-band radiant intensity, spectral radiant intensity and a spatial radiance map.
POC AFIWC/DBE, Mr. Larry Oakes, 210-977-2057

Strategic and Theater Attack Modeling Process (STAMP): STAMP is a ballistic missile and space launch vehicle flight generator and engineering analysis tool. It can model missile flights from launch to impact and present extensive flight characteristics and trajectory descriptions using a wide array of graphical and tabular outputs. STAMP can also model numerous US and foreign space launch vehicles from launch to orbital insertion. STAMP features an easy-to-use operator interface using windows and click-type menu selections. STAMP is driven by detailed engineering data bases, developed and approved by the appropriate intelligence agencies, which contain the parameters and values needed to model strategic and theater missiles as well as foreign space launch vehicles consistent with intelligence estimates. Portions of STAMP have been integrated into the Satellite and Missile Analysis Tool (SMAT) to generate and process foreign

missile trajectories for SMAT users. STAMP was developed by SAIC under the sponsorship of the Air Force National Air Intelligence Center (NAIC).

Strategic and Theater Operations Research Model (STORM): This simulation, the Synthetic Theater Operations Research Model (STORM), will support in-depth analysis of the campaign-level contributions of air and space power. It will provide a robust analytical capability to evaluate the contributions of air and space power in the context of military operations extended in time and space -- i.e., at the campaign level. Accordingly, NASM/AN is developing STORM, a multi-sided, object-oriented, stochastic computer simulation of military operations across the air, space, land, and maritime domains. The simulation is being designed and built expressly to examine issues involving the utility and effectiveness of air and space power in a theater-level, joint warfighting context. In addition, the NASM/AN Program exchanges modeling and computer science expertise with the training simulation community (NASM) and other Service and Joint analytical efforts, promoting the DoD goals of interoperability and re-use. Designed to capitalize on advances in both hardware and software environments, STORM is envisioned as a stand-alone tool as well as a member of a federation. As a direct result of the development of STORM, the NASM/AN Program will provide NASM and the DoD M&S community at large with authoritative representations (objects) of air and space power in a campaign perspective. IOC delivery of version 1.0 is December 2002.
POC USAF/AFSAA http://www.s3i.com/STORM

System Effectiveness Analysis Simulation (SEAS)2: The System Effectiveness Analysis Simulation (SEAS) is a PC-hosted, many-on-many, stochastic, theater-wide, multi-mission-level model. It is typically used for military utility analyses of present and future space systems to explore combat outcome sensitivities to C4ISR (Command, Control, Communication, Computers, Intelligence, Surveillance, and Reconnaissance) operational concepts and force structures. By modeling the explicit causal link from sensor-to-shooter, SEAS is able to show the emergent non-linear behavioral impact of C4ISR on spatial/temporal maneuver and attrition of terrestrial forces. SEAS 2 is a mission model in the AF analysis toolkit (AFSAT) at http://www.xo.hq.af.mil/xoc/xoca/afsat
POC: Capt Eric Frisco (USAF/SMC/XRDM) Eric.Frisco@losangeles.af.mil

Tactical Sensor Planner (TSP): TSP models electronic warfare effects. TSP graphically displays the EC environment to include order-of-battle, the effects of stand off jamming and self-protection jamming and the detection capabilities of ground-based radars. Routes can be generated within TSP and color-coding the analysis points along the route shows an analysis of the flight routing. The model displays line-of-sight (LOS) between threat location and target aircraft flying at any altitude. Terrain masking effects, engagement envelope limits and radar parametrics condition the LOS.
POC AFIWC/SAS, TSgt Justin Bolton, jwbolto@afiwc.osis.gov, 210-977-2729

Thunder: THUNDER is a stochastic, two-sided, analytical simulation of campaign-level military operations developed in the 1980s under the auspices of the Air Force Studies and Analyses Agency (AFSAA). The simulation was designed and built expressly to

examine issues involving the utility and effectiveness of air and space power in a theater-level, joint warfare context. It provides insight into the full range of potential outcomes of a military campaign. THUNDER's ground war combat results were derived from deterministic play of US Army Concepts and Analysis Agency supplied data using the attrition calibration (ATCAL) process. THUNDER is a data driven model. Scenarios, force structure, terrain, and weapon systems are described in input data. Emphasis is placed on traceability of data back to intelligence/service documents or lower level model outcomes. THUNDER is a stochastic model, which supports Monte Carlo simulation and statistical inference. Thunder is a campaign model in the AF analysis toolkit (AFSAT) at http://www.xo.hq.af.mil/xoc/xoca/afsat
Model manager, Capt Thuan Tran (USAF/AFSAA) thunder.modelmgr@pentagon.af.mil

Target Prioritization for Links & Nodes (TPT-LN) {Formerly SIAM): TPT-LN analyzes information flows on the battlefield to determine effects-based target priorities and information degradation from weapon use. It models a network of sensors and shooters and the paths that connect them. It displays communications paths, identifies choke points, prioritizes targets, analyzes strategies/courses of action, and identifies intelligence collection shortfalls. It is an automated decision support tool to assess system vulnerabilities and plan for effective employment of air and space forces at the JTF and JFACC. TPT-LN assists in ranking both terrestrial and space targets to produce an integrated Candidate Target List (CTL) and assessing the value of information to both Red and Blue commanders.
POC Capt Brett Johnson USAF/SWC/DOY

Warning: Warning is a PC-based, graphical strategic ballistic missile warning analysis model designed to estimate warning time available to specified targets from launches made from specified geographic areas. Its outputs can be interpreted as the probability that missiles fired from a particular area were detected and reported.
POC NORAD, Dr. Murray Dixson, murray.dixson@peterson.af.mil, 719-554-3781

Please send catalog additions and updates to MAJ Bill McLagan, USSPACECOM/AN, 719-554-5122, DSN 692-5122, bill.mclagan@peterson.af.mil

BIBLIOGRAPHY

Aegis Research Corporation, *Site Visit for Discussion of Target Prioritization Tool for Links and Nodes* (TPT-LN), {Formerly SIAM}. August 2002.

Bush, George W., *President Discusses National Missile Defense*. Remarks by the president on National Missile Defense, Rose Garden, 13 December 2001. Available Internet: http://www.whitehouse.gov/news/releases/2001/12/20011213-4.html

Carey, Steven D. *An Executive Guide to Space: A Starting Point for Understanding Space in the New Millennium*. Washington DC: Rand 2000.

Chairmen, Joint Chiefs of Staff. *1998 CJCS Master Positioning, Navigation, and Timing Plan*. Washington DC. Available Internet: http://www.spacecom.af.mil/usspace/gps_support/documents/MasterNav&TimingPlan.pdf. 13 February 1998.

Commission to Assess United States National Security Space Management and Organization, *Report of the Commission to Assess United States National Security Space Management and Organization*. 2001.

CNN Internet News. *Leonids light up the sky, threaten satellites*. Available Internet: http://www.cnn.com/TECH/space/9811/17/leonids.02/#3. 13 December 2001.

Department of the Air Force. *AF2025*. 1998.

Department of the Air Force. *SPACECAST 2020*. Volume 1, Maxwell Air Force Base AL: Air University Press 1994.

Department of the Air Force. *Space Handbook: An Analyst's Guide*. Volume 2, Maxwell Air Force Base AL: Air University Press 1993.

Department of the Air Force. *Space Handbook:, A Warfighter's Guide to Space*. Volume 1, Maxwell Air Force Base AL: Air University Press 1993.

Department of the Air Force. *Long Range Plan*. United States Space Command 1998. Available Internet: http://www.peterson.af.mil/usspace/LRP/cover.htm

Department of Defense, Assistant Secretary of Defense for C3I. *Space Technology Guide*. 2001. Available Internet: http://www.fas.org/spp/military/myer.pdf

Department of Defense, Assistant Secretary of Defense for C3I. *Global Positioning System Standard Positioning Service Performance Standard*. October 2001.Available Internet: http://www.spacecom.af.mil/usspace/gps support/documents/GPS_Signal_Spec.pdf.

Department of Defense, *Directive 3100.10, Space Policy*. Implementation of PDD-NSC-49/NSTC-8 *National Space Policy*. July 9, 1999.

Department of Defense, *JWARS Executive Overview*. Joint Staff/J-8/SAMD, August 27, 2001.

Dias, William C. *GPS System Segments*. Poughkeepsie NY. Available Internet: http://giswww.pok.ibm.com/gps/gpsweb.html#Header_5. 12 June 1998.

Eberhart, Ralph E. General. Statement to United States Senate Armed Services Committee, Strategic Subcommittee, Washington DC. 8 March 2000.

Federal Radionavigation Plan, Available Internet: http://www.spacecom.af.mil/usspace/gps_support/documents/frp_1999.pdf. 1999.

GPS Support Center (GSC) Website, Available Internet: http://www.spacecom.af.mil/usspace/gps_support/. 9 February 2002.

Harter, Mark E. *Rapid Dominance, Integrating Space into Today's Air Operations Center*. Air Command and Staff College, Wright Flyer Paper No. 11, Maxwell AFB AL: Air University Press 2000.

Hartman, James K. *High Resolution Combat Modeling*. Ed by LTC Jack Kloeber and Lt Col Jack Jackson, AFIT, Wright-Patterson AFB OH, 27 March 1997.

Houck, J.B. *GPS Timing System Warns Airports of Rough Weather*. Available Internet: http://www.wirelessnewsfactor.com/perl/story/9820.html. 27 September 2001.

HQ AFSPC, *Concept of Operations for the Global Positioning System*. 28 December 2001.

Huang, J.H. *Sun-Tzu, The Art Of War*. Quill William Morrow, New York, 1993.

Interagency GPS Executive Board (IGEB). Available Internet: http://www.igeb.gov/ .

Jackson, Jack A., Jones Brian L., Lehmkuhl, Lee J. *2025 Operational Analysis*. 1996.

Klotz, Frank G. *Space, Commerce, and National Security*. New York NY: Council on Foreign Relations Press 1998.

Law, Averill M., Kelton, David W. *Simulation Modeling and Analysis*. 3rd ed. McGraw-Hill, New York, 2000.

Leinart, James A. *A Network Disruption Modeling Tool.* MS thesis, AFIT/GOR/ENS/98M-15. School of Engineering, Air Force Institute of Technology (AETC), Wright-Patterson AFB OH, March 1998.

Litton. *F-15E Guidance and Control Systems*. Available Internet: http://www.littongcs.com/products/2guidance/traditional/ln94/tech.html. 24 Feb 2002.

Mantz, Michael R. *The New Sword, A Theory of Space Combat Power*. Maxwell Air Force Base AL: Air University Press 1995.

McLagan, Bill Maj. *Space, Missile Defense, & Information Operation Modeling and Simulation Catalogue*. 1 August 2001. Available Internet: http://www.msiac.dmso.mil/spug_documents/Space_MS_Catalog_1_Aug_01.doc

McLean, Aldasdair W. M. *The Military Utility of Space*. Centrepiece 19, Centre for Defense Studies, Aberdeen, Scotland, 1991.

Meredith and Mantel, *Project Management, A Managerial Approach*. 4th ed. New York, John Wiley & Sons, 2000.

Montgomery, Douglas C. *Design & Analysis Experiments.* 2nd ed. New York, John Wiley & Sons, 1984.

Murthy and Page. *Mathematical Modeling* New York, Pergamon Press, 1990.

NAVSTAR Global Positioning System Joint Program Office. *GPS System and Technology* Overview. Available Internet: https://gps.losangeles.af.mil/gpsarchives/1000-public/1300-lib/documents/overviews/intro_gps.pdf . July 2000.

Nicholas, John M. *Project Management for Business and Technology Principles and Practice*. 2nd ed. Upper Saddle NJ, Prentice Hall Inc., 2001.

Neter, Kutner, NachtSheim, Wasserman. *Applied Linear Statistical Models*. 4th ed. New York, McGraw-Hill, 1996.

Newberry, Robert D. *Space Doctrine for the Twenty-first Century*. Maxwell Air Force Base AL: Air University Press 1998.

Odenwald, Sten. *Solar Storms*. Special to The Washington Post, Wed, March 10, 1999; Page H01. Available Internet: http://solar.physics.montana.edu/press/WashPost/Horizon/196l-031099-idx.html

Payne, Robert, Jr. *Modeling Space in the Air Force Command Exercises System (ACES)*. MS thesis, AFIT/GOA/ENS/96M-04. School of Engineering, Air Force Institute of Technology (AETC), Wright-Patterson AFB OH, March 1996.

Siegel, Lee. *Geomagnetic Storm Sparks Northern Lights*. Space.com, Available Internet: http://www.space.com/scienceastronomy/aurora_sightings_000814.html 13 Dec 2001.

SMC Fact Sheet. *NAVSTAR Global Positioning System*. Available Internet: http://www.losangeles.af.mil/SMC/PA/Fact_Sheets/gps_fs.htm. May 2000.

The White House, *Presidential Decision Directive NSTC-6*. Available Internet: http://www.spacecom.af.mil/usspace/gps_support/documents/gps_pdd.htm 28 March 1996.

Thompson, Richard. *Power Failure in Canada During 1989*. IPS Radio & Space Services. http://www.ips.gov.au/papers/richard/power_1989.html 27 September 2001.

Rand Corporation, *Appendix A: System Effectiveness Analysis Simulation (SEAS).* Available Internet: http://www.rand.org/publications/DB/DB339/DB339.appa.pdf 13 March 2002.

Rayno, Bruce. *A Methodology To Assess The Utility Of Future Space Systems*. MS Thesis, AFIT/GSO/ENS/94D-14. School of Engineering, Air Force Institute of Technology (AETC), Wright-Patterson AFB OH, December 1994.

Rosenau, Milton. *Successful Project Management*. Lifetime Learning Publications, Belmont CA. 1981.

Rueters. *Sun Storm Dies Down*. ABC News Online, Available Internet: http://abcnews.go.com/sections/science/dailynews/solarflare000717.html 27 Sept 2001.

Ravindran, A., Phillips, Don T., and Solberg, James J. *Operations Research Principles and Practice 2nd ed.*, John Wiley & Sons, New York, 1987.

Veridian. *Analysts Manual Version 2.0.0*. Control Number 63622-01U. Dayton OH. June 2001.

Veridian. *Users Manual Version 2.0.0*. Control Number 63621-01U. Dayton OH. June 2001.

Wallace, Karilynne. *Multi-Discipline Network Vulnerability Assessment.* MS thesis, AFIT/GSO/ENS/99M-01. School of Engineering, Air Force Institute of Technology (AETC), Wright-Patterson AFB OH, March 1999.

Wallam, Jon. CEP formula provided by Steve Glazewski of Veridian. Site Visit. 15 January 2002.

Walter, Pincus. *Tenet Says Al Qaeda Still Poses Threat*. The Washington Post Online, Available Internet: http://www.washingtonpost.com/wp-dyn/articles/A32021-2002Feb6.html 7 February 2002.

Watts, Barry. *The Military Use of Space: A Diagnostic Assessment*. Taken from the Center for Strategic and Budgetary Assessments web site. pg. http://www.csbaonline.org/4Publications/Archive/H.20010111.The_Military_Use_o/H.20010111.The_Military_Use_o.htm. 3 July 2001.

Whitsel, Lynette T. Lt Col, USAF. AFSPC/XPXA, Peterson AFB CO. Interview. 9 Aug 2001.

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14. ABSTRACT

This research is a framework for understanding issues in modeling the military aspect of space, with particular regard to capturing its value. Space power is a difficult and far-reaching topic, with implications that go beyond the military aspects. The United States military increasingly relies on space-based systems and information for success in daily operations. Telecommunications, navigation and timing, intelligence, surveillance, reconnaissance, and weather prediction are instances of services that have become dependent on satellite systems. If this reliance on space is not fully understood, U.S. national security will be at risk as the result of space information degradation or denial. This research effort attempts to break new ground in organizing the interactions and interdependencies among space doctrine, space systems, system owner/operators, and space-based information users. An illustrative example, using GPS, is then examined to explore the approach. Analysis of GPS as it affects JDAM accuracy is modeled using the GPS Interference And Navigation Tool (GIANT).

15. SUBJECT TERMS

Military Worth, Space Worth, Global Positioning System, GPS, Space modeling, Military space modeling

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